

PATENT
Customer No. 22,852
Attorney Docket No. 9314.0046-00

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:)
)
Michael John DIXON et al.) Group Art Unit: 2834
)
U.S. Application No.: 10/589,684) Examiner: Not Yet Assigned
)
International Appl. No. PCT/GB2005/000320)
) Confirmation No.: 9914
International Filing Date: January 31, 2005)
)
For: POSITIONER DEVICE)

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

RESPONSE TO NOTIFICATION OF MISSING REQUIREMENTS AND PETITION FOR FILING DECLARATION UNDER 37 C.F.R. § 1.47(a) - NON-SIGNING INVENTOR

Applicants now respond to the Notification of Missing Requirements Under 35 U.S.C. 371 mailed March 20, 2008 ("Notification"), the period for reply having been extended five months through October 20, 2008, by the accompanying Petition for Extension Time and authorization for the Commissioner to charge the extension of time fee of \$2,350.00, the additional claim fee of \$442.00, and the surcharge fee of \$130.00 to Deposit Account No. 06-0916.

Applicants submit a signed Declaration and Power of Attorney document for filing in the above-referenced application and a copy of the Notification. Applicants also enclose an

Information Disclosure Statement.

10/08/2008 LLANDGRA 00000019 060916 10589684

01 FC:1617	130.00 DA
02 FC:1615	52.00 DA
03 FC:1616	390.00 DA

Pursuant to 37 C.F.R. § 1.47(a), Applicants hereby petition that the attached Declaration, executed by inventor Michael John Dixon be accepted by the U.S. Patent and Trademark Office on behalf of himself and non-signing inventor Terence James Herbert.

The pertinent facts concerning Mr. Herbert's refusal to join this application are set forth in the attached Declaration of Keith Dhese, and my accompanying declaration. Mr. Herbert's last known address is: 75 Pelham Way, Cottenham, Cambridgeshire CB4 8YQ, United Kingdom.

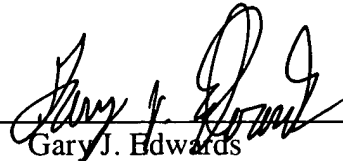
Please grant any further extension of time required to enter this response, and charge any additional required fees to Deposit Account No. 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: October 3, 2008

By: _____


Gary J. Edwards
Reg. No. 41,008
650.849.6622

EXPRESS MAIL LABEL NO. EM 100825235 US



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P.O. Box 1450
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Sir:

DECLARATION OF GARY J. EDWARDS, PH.D.

I, Gary J. Edwards, Ph.D., do hereby make the following declaration:

1. I am a partner at the law firm of Finnegan, Henderson, Farabow, Garrett, & Dunner, LLP.
2. On August 16, 2006, I filed the subject patent application in the USPTO pursuant to 35 U.S.C. § 371 on behalf of Melles Griot Limited, subsequently assigned to Thorlabs, Inc. The application names Michael John Dixon and Terence James Herbert as inventors.
3. On July 1, 2008, the undersigned sent a letter dated June 30, 2008, by the United States Postal Service International Registered Mail Service and Return Receipt Requested for International Mail to Terence James Herbert at his last known home address, 75 Pelham Way, Cottenham, Cambridgeshire CB4 8YQ, United Kingdom. In the letter, the undersigned instructed Mr. Herbert to "return the signed documents to us as early as possible, but preferably by July 20, 2008." Enclosed with this letter were:

- 1) A Declaration and Power of Attorney for his signature;
- 2) An Assignment of Patent Application for his signature; and
- 3) A copy of the specification, claims, and abstract.

A copy of the letter with the enclosures is attached at Tab 1 (39 pages).

4. On July 1, 2008, the undersigned sent an identical letter dated June 30, 2008, by the United States Postal Service International Registered Mail Service and Return Receipt Requested for International Mail to Terence James Herbert at another last known address on record to 15 Clipped Hedge, Hatfield Heath, Hertfordshire CB6 2EW, United Kingdom. In the letter, the undersigned similarly instructed Mr. Herbert to “return the signed documents to us as early as possible, but preferably by July 20, 2008.” Enclosed with this letter were:

- 1) A Declaration and Power of Attorney for his signature;
- 2) An Assignment of Patent Application for his signature; and
- 3) A copy of the specification, claims, and abstract.

The letter sent to the above address was not returned by the Royal Mail Service, and delivery was also not acknowledged. A copy of the letter with the enclosures is attached at Tab 2 (39 pages).

5. On July 8, 2008, the Royal Mail Service returned the package to the undersigned in Palo Alto, CA, as they “were unable to deliver this item because addressee has gone away”, A copy of the mailing envelope is attached at Tab 3 (1 page).

6. On July 30, 2008, the undersigned re-sent the previous letter (referenced in item #3) now re-dated July 30, 2008, by the United States Postal Service International Registered Mail Service and Return Receipt Requested for International Mail to Terence James Herbert at his last known home address, 75 Pelham Way, Cottenham, Cambridgeshire CB4 8YQ, United Kingdom. In the letter, the undersigned instructed Mr. Herbert once again to “return the signed documents to us as early as possible.” Enclosed with this letter were:

- 1) A Declaration and Power of Attorney for his signature;
- 2) An Assignment of Patent Application for his signature;
- 3) A copy of the specification, claims, and abstract; and

A copy of the letter with the enclosures is attached at Tab 4 (39 pages).

7. On August 8, 2008, the Royal Mail Service returned the package to the undersigned in Palo Alto, CA, as "addressee unknown", A copy of the mailing envelope is attached at Tab 5 (1 page).

8. Copies of the United States Postal Service receipts dated July 1, 2008, and July 30, 2008, for International Registered Mail Service and Return Receipt Requested for International Mail service, attached at Tab 6 (2 pages).

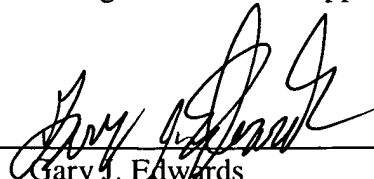
9. A copy of Mr. Herbert's employment agreement with Melles Griot is attached at Tab 7 (4 pages).

10. Based on the fact that Mr. Herbert has not responded to any of those letters, it is my opinion that Mr. Herbert is refusing to sign, or can not be found.

I further declare that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true, and understand that willful false statements and the like are punishable by fine or imprisonment, or both (18 U.S.C. 1001), and may jeopardize the enforceability of any patent issuing from the '684 application.

Dated: October 3, 2008

By: _____


Gary J. Edwards
Reg. No. 41,008
650.849.6622

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Cambridgeshire CB6 2EW (GB). HERBERT, Terence, James [GB/GB]; 75 Pelham Way, Cottenham, Cambridgeshire CB4 8TQ (GB).

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(71) Applicant (for all designated States except US): **THORLABS, INC. [US/US]; 435 Route 206 North, Newton, NJ 07860 (US).**

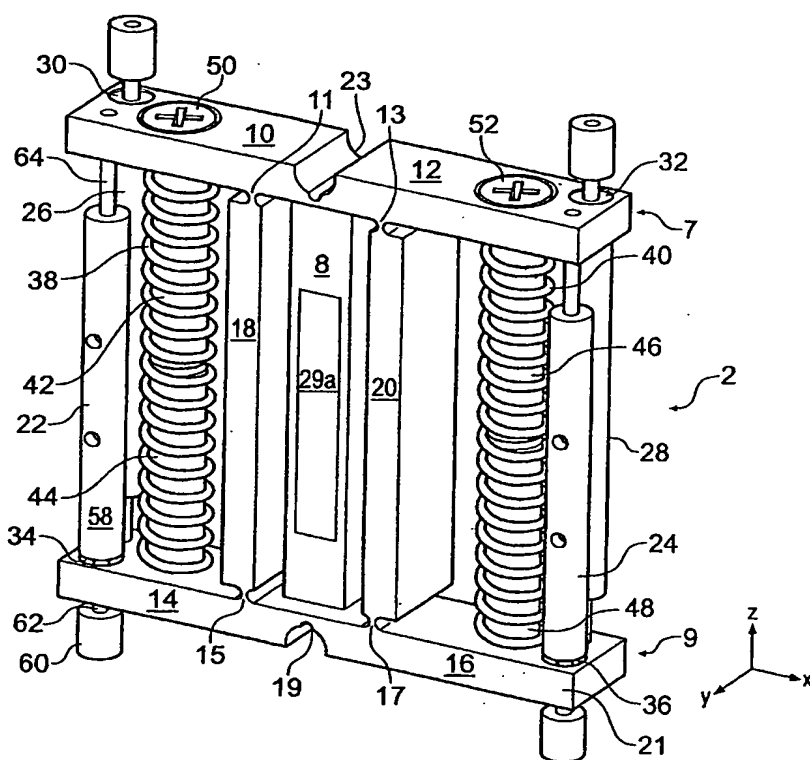
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(72) Inventors; and

(75) Inventors/Applicants (for US only): **DIXON, Michael, John [GB/GB]; "A" Furlong Drove, Little Downham, Ely,**

[Continued on next page]

(54) Title: **POSITIONER DEVICE**



(57) Abstract: A positioner (2) for moving a sample platform (6) relative to a base (4) is described. The positioner is driven by a piezoelectric arranged to expand and contract along a drive axis, the piezoelectric element has an input end coupled to the base and an output end coupled to first (14) and second (16) output levers extending away from the drive axis of the piezoelectric element in opposing directions. The output levers each have an inner arm arranged to be acted on by the piezoelectric element as it expands and an outer arm to which the sample platform is mounted via platform supports (26, 28). The output levers are mounted such that the piezoelectric element acts on the inner arms of the output levers to cause the outer arms to move in a plane containing the drive axis. This motion of the output levers is communicated via the platform supports to the sample platform, so moving it relative to the base along a direction parallel to the drive axis.

European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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POSITIONER DEVICE

BACKGROUND OF THE INVENTION

5 The invention relates to positioners which are widely used for a variety of applications including the positioning of optical components, both in production lines and in scientific experiments.

One shortcoming of positioners designed to provide a high degree of accuracy in their positioning is that they are often only able operate over a relatively limited range. For example, a number of positioner designs employ piezoelectric drive
10 elements in their drive mechanisms. Piezoelectric drive elements are useful because they are relatively robust and are able to provide repeatable high precision positioning. However, a 38 mm long piezoelectric stack might have a positioning range of only 42 μm . This limited range can mean positioners employing piezoelectric drive elements can be impractical for many applications. Similar problems can arise with other types
15 of high precision drive mechanisms.

US 3 902 084 [1] and US 3 902 085 [2] describe "inchworm positioners" which address this problem. These are one-axis positioners arranged to selectively grip and release opposing ends of a piezoelectric drive element as it is cyclically expanded and contracted. Appropriate control of the piezoelectric drive element and
20 the piezoelectric grips at either end can cause the piezoelectric drive element to inch its way along between the grips during successive expand and contract cycles. Although positioners of this type allow for larger ranges of motion, they are complex designs requiring a number of moving parts which must be separately controlled in a carefully orchestrated manner.

25 Another approach is to use a positioner comprising two elements in frictional engagement with one another which slide relative to one another when the frictional force between them is overcome. Motion is generated by the interplay between inertia of one of the elements and slipping or sticking of the frictional engagement between the elements. Positioners of this kind are referred to as inertial positioners or slip-stick

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positioners and are known for example from an article by Dieter Pohl in the journal "Review of Scientific Instruments" [3]. Inertial slip-stick positioners can be made with relatively few major components. However, known inertial slip-stick positioners have a low load bearing capacity and a high degree of sensitivity to orientation, unlike the above described inchworm positioners.

An alternative solution would be to use a lever arrangement to magnify or amplify the motion. JP 02 119277 [4] describes a mechanical amplifier for a piezoelectric drive element, albeit one designed primarily for dot-matrix printer heads. The device of JP 02 119277 employs a pair of hinged levers mounted at opposing ends of a piezoelectric stack such that the lever's outer arms are brought together as their inner arms are pushed apart by the piezoelectric element expanding. A buckle spring connects between the lever's outer arms and buckles outwardly as the lever arms are brought together. The outward motion of the buckle spring provides the useful output of the device. EP 0 510 698 [5] employs principles similar to those of JP 02 119277, but has two buckle springs connected in series between the levers. This provides for two simultaneous displacement outputs. Devices of this kind are not generally suitable for the reliable positioning of sample platforms. This is because their sprung nature makes them prone to vibration, and their buckling movement will generally be different for different platform loads. This means samples having different masses will generally be positioned differently for the same expansion of the piezoelectric drive element.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a positioner comprising: a base and a sample platform moveable relative to the base; a drive
5 mechanism arranged to act between the base and the sample platform; and a plurality of levers extending away from each other, the levers supporting the sample platform and being connected to the drive mechanism so that actuation of the drive mechanism is transmitted under mechanical advantage of the levers to position the sample platform.

10 The use of levers allows the motion of the drive mechanism, for example the expansion or contraction of a piezoelectric element, to be amplified before being transmitted to the sample platform. Furthermore, by mounting the sample platform on a plurality of levers extending away from each other, a stable mounting can be achieved which is resistant to torque forces applied by the weight of a sample on the
15 sample platform, for example where the sample is located off-centre. In addition, the use of a plurality of levers allows the arcuate motions associated with each of the individual levers to be combined to provide a linear motion of the sample platform.

Throughout the following, the levers will sometimes be referred to as output levers. This term reflects that they support the sample platform, which may be
20 considered an output stage of the positioner.

Each lever can be rotatably mounted on a fulcrum which subdivides the levers into inner and outer arms with the inner arms being connected to the drive mechanism and the outer arms supporting the sample platform.

This allows for simple lever and drive mechanism configurations. However, it
25 will be appreciated that other configuration are possible. For example, the sample platform and drive mechanism may both be coupled to the output arms, the relative locations of their couplings determining the mechanical advantage.

The drive mechanism may be arranged to act on each of the levers in the same direction such that they move in a similar manner to one another when the drive
30 mechanism is actuated.

The plurality of levers may comprise two levers extending in opposing directions.

The levers may be connected to one another by a flexible hinge. The flexible hinge may be a leaf spring connecting between the levers, for example, or the levers
5 may be formed from a single cross member. The flexible hinge being provided by a thinned section of the cross member.

Connecting the levers in this way provides a restoring force as each of the levers are pivoted about their fulcrums, sometimes referred to as flexible pivots, away from their rest positions. This restoring force provides a support force for the sample
10 platform. By forming the levers from a single cross member, a structurally robust and easy to assemble configuration having a low number of parts can be provided.

Support walls may be used for pivotably supporting the levers at their fulcrums, the levers being connected to the support walls by flexible connections providing the fulcrums which allow them to pivot. Furthermore, each lever and its
15 support wall may be of unitary construction with the flexible connections being provided by thinned sections at the junctions between the levers and support walls.

This kind of flexible pivot provides a further restoring force as each of the levers are pivoted, so increasing the support force for the sample platform. The unitary construction is structurally robust and easy to assemble having a low number of parts.

20 The support walls providing the flexible pivot support may be configured to be independently flexed. For example, a piezoelectric transducer may be bonded to a face of one of support walls which can be driven to expand, so causing the support wall to flex. Flexing one or other (or both) support walls reduces their effective length relative to one another. This can cause relative movement between the fulcrums of the
25 different levers. Because the sample platform is connected to each of the levers, this relative movement between the fulcrums leads to a rotation of the sample platform with respect to the base, so allowing for angular positioning.

The sample platform may be mounted on the levers by a pair of output linkages which are stiff in respect of forces applied parallel to their axes of extent.
30 This allows motion to be reliably transferred from the levers to the sample platform.

The output linkages may be deformable in respect of forces applied transverse to their axes of extent. This assists the positioner to accommodate the transverse components of the arcuate motion of the levers and so provide the linear motion of the sample platform. In other cases, resilient mountings between the output linkages and the levers and/or the sample platform may be provided to accommodate these transverse motion components.

The flexible output linkages allow the positioner to reliably position the sample platform parallel to the drive axis, even if the sample platform is being moved or is offset relative to the base in a direction which is transverse to the drive axis, the transverse movement being accommodated by flexure of the output linkages. This allows a number of the positioners to be connected in parallel in a multi-axis positioner. For example, two or three orthogonally mounted positioners may be connected between a common base and a common sample platform to provide a two- or three-axis positioner.

The output linkages may extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.

The output linkages may extend away from the levers on the same side as that on which the drive mechanism, or a significant part of it, is located.

This "doubling-back" of the output linkages allows the use of relatively long output linkages in a small space. The use of long output linkages improves their flexibility. In addition, long output linkages provide for a relatively large radius of curvature for the transverse motions associated with either the arcuate motion of the levers, or the transverse motion of the sample platform relative to the base in a multi-axis positioner. Having a large radius of curvature acts to reduce the coupling between the transverse and longitudinal components of the motion of the positioner.

The positioner may further comprise biasing elements, for example springs, e.g. helical springs, connected to each lever and arranged to resist movement of the levers relative to the base. The biasing acts to provide an additional restoring force for the levers as they are moved by the drive mechanism. This further increases the load which the positioner can reliably support and position.

The positioner may further comprise a stop mechanism connected to each lever to limit the amount by which it can move relative to the base. This helps to prevent the positioner from being damaged, for example by being overloaded or over driven by the drive mechanism.

5 In general, the geometry of the levers and the locations at which the sample platform and the drive mechanism are coupled to them, will be such that the sample platform moves by an amount greater than an amount by which the drive mechanism moves. That is to say the mechanical advantage, or mechanical amplification, of the lever's action will be greater than unity. However, in some examples the arrangement
10 will be such the sample platform moves by an amount less than an amount by which the drive mechanism moves. That is to say the mechanical advantage, or mechanical amplification, of the lever's action will be less than unity. This arrangement effectively gears-down the expansion or contraction of the piezoelectric element. This allows a sample to be positioned more accurately than the drive mechanism precision.

15 The positioner may include one or more strain gauges for measuring the position of the levers. There are a number of points at which strain gauges may be mounted. For example, strain gauges may be coupled to the parts drive mechanism. For example, they may be bonded to the side of a piezoelectric element which might form part of the drive mechanism. This allows the movement of the drive mechanism
20 to be measured, from which the positions of the levers can be calculated. From the positions of the levers, the position of the sample platform relative to the base can be determined. Strain gauge output signals can also be used in a feed back control loop to improve the positioning stability, i.e. to provide an encoder device.

25 The one or more strain gauges may be coupled to respective bridge measuring circuits. For example, Wheatstone bridge measuring circuits, which are mounted on the positioner itself. This can help to reduce effects arising from temperature differentials between different elements of the bridge circuitry. In some embodiments, a strain gauge may be used in each arm of the bridge circuitry to provide increased sensitivity.

30 The positioner may include a further plurality of levers extending away from each other, the further levers being connected to the base and the drive mechanism so

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that actuation of the drive mechanism is transmitted to the further levers to cause them to move with respect to the base.

Each further lever may be rotatably mounted on a fulcrum, thereby subdividing the further levers into inner and outer arms with the inner arms connected
5 to the drive mechanism and the outer arms connected to the base.

The further levers may be arranged such that the drive mechanism acts on each of the further levers in the same direction. This may be a direction which is different to that in which the drive mechanism acts on the first mentioned, or output, levers.

Throughout the following, the further levers will sometimes be referred to as
10 input levers. This term reflects that they are coupled to the base, which may be considered an input stage of the positioner.

The input levers generally mirror the output levers and so provide a positioner with a high degree of symmetry. It will be understood that the design and construction of the input levers may include a number of features which correspond to those
15 described above for the output levers.

A pair of input linkages may be used for connecting the base to the input levers, the input linkages being stiff in respect of forces applied parallel to their axes of extent but deformable in respect of forces applied transverse thereto. The input linkages may again be doubled-back, i.e. extending away from the input levers on the
20 same side as that on which the drive mechanism is located, to allow for long linkages in a small space.

By providing a highly symmetric design such as this, movement of the drive mechanism can be transferred to the sample platform via a combined motion of the output and input levers. This means the output levers only need pivot by
25 approximately half the amount they would otherwise do if there were no input levers to accommodate part of the motion of the drive mechanism. This reduces residual effects associated with the arcuate motion of the levers.

The highly symmetric design additionally reduces the number of different component parts of the positioner, so providing for more simple manufacture.

30 According to a second aspect of the invention there is provided a multi-axis positioner comprising a first positioner according to the first aspect of the invention

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aligned along a first direction and a second positioner according to the first aspect of the invention aligned along a second, different, direction, the first and second positioners connecting between a common base and a common sample platform.

5 The multi axis-positioner may further comprise a third positioner according to the first aspect of the invention aligned along a third direction, the third direction being different to the first and second directions, the third positioner connecting between the common base and the common sample platform.

10 In this way, a multi-axis positioner having a parallel mechanism may be provided having up to six degrees of freedom. Where six degrees of freedom are not required, fewer may be provided. For example, the third positioner might not provide for rotation of the sample platform, such that a five-axis positioner is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention and to show how the same may be carried into effect reference is now made by way of example to the accompanying
5 drawings in which:

Figure 1 schematically shows a front view of a one-axis positioner according to a first embodiment of the invention;

Figure 2 schematically shows an end view of the positioner shown in Figure 1;

Figure 3 schematically shows a side view of the positioner shown in Figure 1;

10 Figure 4 schematically shows a perspective view of the positioner shown in Figure 1;

Figure 5 schematically shows a flexible linkage of the positioner shown in Figure 1;

15 Figure 6 schematically shows a perspective view of a three-axis positioner according to a second embodiment of the invention; and

Figure 7 schematically shows an exploded perspective view of a base and a sample platform for the positioner shown in Figure 6.

DETAILED DESCRIPTION

Figures 1, 2, 3 and 4 schematically show respective front, end, side and perspective views of a positioner 2 according to a first embodiment of the invention.

- 5 The positioner 2 is described with reference to a three-dimensional Cartesian coordinate system and terms such as upper and lower refer to the orientation shown in Figure 1. It will be appreciated, however, that the positioner can be equally be used in other orientations. The front view of Figure 1 is taken along a y-axis, the end view of Figure 2 is taken along a z-axis and the side view of Figure 3 is taken along an x-axis.
- 10 A legend in each figure indicates the Cartesian plane of the figure.

The positioner 2 is a one-axis positioner for moving a sample platform (or output stage) 6 relative to a base (or input stage) 4 along the z-axis. (The sample platform 6 is not shown in Figures 2 or 4 and the base 4 is also not shown in Figure 4). The positioner in this example has a characteristic size of around 55 mm in the x- and z-directions and about 15 mm in the y-direction. However, it is noted the design is inherently scaleable so these dimensions could be much smaller or larger if desired. In fact, the design could be useful for a micro-electromechanical system (MEMS) or nano-technology environment implemented in semiconductor materials using etch technology. The positioner comprises a main body member 21 made of stainless steel,

15 a piezoelectric element 8, a pair of input flexible linkages 22, 24 connecting the main body 21 to the base 4, a pair of output flexible linkages 26, 28 connecting the main body 21 to the sample platform 4, load springs 38, 40 and mounting spigots 42, 44, 46, 48 for the load springs. The piezoelectric element 8 is schematically illustrated as a stack, but it will be understood that a tube or other form of piezoelectric element

20 could be used. Other kinds of actuator, such as a driven screw, may also be used.

In this example, the main body 21 is of unitary construction and comprises an input cross member 7 to which the input flexible linkages 22, 24 are attached and an output cross member 9 to which the output flexible linkages 26, 28 are attached. The input and output cross members 7, 9 are separated from one another by first and second support walls 18, 20. The input cross member 7 has a cut-out in its upper face running parallel to the y-axis. This provides for an input flexure hinge 23 which

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allows the input cross member to flex at its centre. The output cross member 9 has a similar cut-out in its lower face. This provides for an output flexure hinge 19 which allows the output cross member to flex at its centre. The connections between the respective ends of the first and second support walls 18, 20 and the input and output cross members 7, 9 comprise thinned sections of the main body 21 extend along the y-direction so as to provide respective flexure pivots 11, 13, 15, 17 which act as fulcrums.

The combination of flexure hinges 23, 19 in the cross members 7, 9 and the flexure pivots 11, 13, 15, 17 provide for four levers 10, 12, 14, 16. The input cross member 7 is divided by its flexure hinge 23 into a first input lever 10 and a second input lever 12 with respective ones of the flexible pivots 11, 13 providing fulcrums for each of the input levers. The output cross member 9 is divided by its flexure hinge 19 into a first output lever 14 and a second output lever 16 with respective ones of the flexible pivots 15, 17 providing fulcrums for each of the output levers. Accordingly, the input and output levers to one side of the piezoelectric element 8 form a first opposing pair of input and output levers 10, 14 while the input and output levers to the other side of the piezoelectric element 8 form a second opposing pair of input and output levers 12, 16. Each lever 10, 12, 14, 16 is subdivided by its respective flexible pivot 11, 13, 15, 17 into an inner arm and an outer arm. The inner arms of the levers are those parts extending inwardly from the flexible pivots towards the flexure hinges. The outer arms are those parts of the levers extending outwardly away from the flexure hinges.

The piezoelectric element 8 extends between the input and output cross members 7, 9 and is positioned between the support walls 18, 20. The piezoelectric element is arranged so as to expand and contract along the z-axis when driven by an appropriate drive signal. The piezoelectric element has an input end adjacent the input cross member 7 and an output end adjacent the output cross member 8. The interfaces between the ends of the piezoelectric element 8 and the cross members 7, 9 are arranged such that the cross members may flex at their flexure hinges without damaging the piezoelectric element. This can be achieved, for example, by employing a bearing pad having a limited contact area aligned with the flexure hinges of the cross

-12-

members. The piezoelectric element 8 is dimensioned slightly longer than the gap into which it is to be placed. The piezoelectric element is inserted into this undersized gap by first forcing the outer arms of opposing pairs of the input and output levers together. This causes the levers 10, 12, 14, 16 to pivot about their respective flexure pivots 11, 13, 15, 17 such that the gap into which the piezoelectric element is fitted is increased, and the piezoelectric element can be inserted. Once the piezoelectric element is in place, the force applied to the outer arms of the levers is removed so that the main body attempts to re-adopt its unstressed configuration. However, it is prevented from doing so fully by the additional length of the piezoelectric element. This ensures the piezoelectric element is kept under compression. This pre-stressing of the piezoelectric element improves its operating characteristics, as is well known.

A strain gauge is bonded to each side of the piezoelectric element. Three of the strain gauges 29a, 29b, 29c can be seen in Figure 1. Each strain gauge is configured to measure the degree of expansion or contraction of the piezoelectric element 8. It will be appreciated that the expansion or contraction of the piezoelectric element 8 could be measured using other strain gauge configurations. For example, only one strain gauge might be used. However, multiple strain gauges can provide improved sensitivity.

Figure 5 is a schematic cross-section view of one of the input flexible linkages 22 used to connect the input cross member 7 to the base 4. The other flexure linkages 24, 26, 28 are identical in structure to the flexure linkage 22 shown in Figure 5, although are differently installed in the positioner 2. The linkage is rigid in respect of forces applied along its axis of extent, but flexible in respect of transversely applied forces. It will be appreciated that in some single axis embodiments of the invention, the flexible linkages 22, 24, 26, 28 could be replaced with rigid linkages which are not deformable in respect of transversely applied forces. However, as will be seen further below, flexible linkages of the kind shown in Figure 5 allow for a positioner which can be easily integrated into a multi-axis positioner. The flexure linkage 22 contains a rigid central body 58 with a mounting dowel 60 attached to one end by a flexible portion 62. A similar flexible portion 64 extends from the other end of the central body but terminates freely. The central body and mounting dowel are made of 3 mm

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diameter stainless steel rod. The flexible portions are made of 1 mm diameter music wire. The mounting dowel is around 5 mm long and the central body is around 25 mm long. The music wire is received into bores in the central body and the mounting dowel such that approximately 10 mm is left exposed between the central body and the mounting dowel and around 15 mm is left exposed on the other side. The flexible linkage 22 has an overall length of around 55 mm. Because the sections of music wire are relatively short, the flexible linkage has a relatively high longitudinal stiffness but is free to flex in the transverse direction. Linkages of this kind are further described in EP 0 937 961 [6].

As can be seen from Figure 4, input flexible linkage 22 is installed in the positioner 2 such that the free-end flexible portion 64 is fixedly connected near the edge of the outer arm of input lever 10. The linkage then extends substantially parallel to the z-axis towards output lever 14, the central body 58 being disposed between the opposing lever arms 10, 14. The flexible portion 62 to which the mounting dowel is attached passes through a rubber bushing 34 in the output lever 14. The rubber bushing 34 allows the input flexible linkage 22 to slide freely in a direction parallel to its axis of extent, but not transversely to this axis. A degree of damping is provided by the rubber bushing and this helps to reduce vibrational noise in the positioner. With the positioner 2 in the orientation shown in Figure 4, the mounting dowel 60 is located beneath the output lever 14. As mentioned above, the base 4 is not shown in Figure 4. However, as can be seen from Figure 1, the mounting dowel 60 is received into an opening in the base where it is held in place, for example by gluing or using grub screws.

The other flexible input linkage 24 is installed in a similar fashion, connecting between the input lever 12 and output lever 14, and passing through rubber bushing 36. The mounting dowel of flexible linkage 24 is similarly attached to the base 4. Accordingly, the positioner 2 is supported with respect to the base 4 by the two input flexible linkages. Because the input flexible linkages are longitudinally rigid, the parts of the outer arms of the input levers to which the input flexible linkages attach are fixed relative to the base along the z-direction. However, because of their flexibility to transverse forces, the parts of the outer arms of the input levers to which the input

-14-

flexible linkages attach may be moved in the x- and y-directions. It will be appreciated that this motion will be arcuate in the xz- and yz-planes respectively, but for ease of explanation, they are described by the direction of their largest component.

The output flexible linkages 26, 28 are installed in an overall similar fashion to the input flexible linkages 22, 24, but, rather than connecting the base to the input levers, they connect the output levers to the sample platform. That is to say, the free end flexible portions of the output flexible linkages are fixedly connected near the edge of the outer arms of respective ones of the output levers 14, 16. The linkages then extend substantially parallel to the z-axis towards input levers 10, 12. For the orientation shown in Figure 4, the mounting dowels of the output flexible linkages are located above the input levers 10, 12. The sample platform 6 is not shown in Figure 4. However, as can be seen from Figure 1, the mounting dowels of the output flexible linkages are received into openings in the sample platform where they are held in place.

Accordingly, the sample platform 6 is supported relative to the base along the z-axis via the output flexible linkages which connect it to the main body 21 which in turn is supported by the input flexible linkages which connect it to the base. The Sample platform is free to move in the x- and y-directions. If this is not desired, support rails or other bracing could be used.

For a positioner in the orientation shown in Figures 1 to 4, the weight of a sample on the sample platform applies a load force which is transmitted from the sample platform 6 along the output flexure linkages 26, 28 so as to act downwardly on the outer arms of the output levers 14, 16. The reaction force supporting the weight of the sample is transmitted from the base 4 along the input flexure linkages 22, 24 so as to act upwardly on the outer arms of the input levers 10, 12. The net effect of this is that opposing pairs of input and output levers are urged apart. This motion is resisted by the resilience of the flexure hinges 17 and 19, the resilience of the flexure pivots 11, 13, 15, 17 and the resistance to compression of the piezoelectric element 8. To increase the useful load that the positioner can support without damaging the flexure hinges, flexure pivot or the piezoelectric element 8 and to provide a positive force against displacements, load springs 38, 40 are used. These connect between the outer

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arms of each opposing pair of input and output levers to provide additional support for the sample platform by effectively increasing the rigidity main body 21. One of the load springs 38 is mounted on a pair of spigots 42, 44 respectively connected to one opposing pair of input and output levers 10, 14. The other load spring 40 is mounted
5 on a similar pair of spigots 46, 48 connected to the other opposing pair of input and output levers 12, 16. The spigots are held in place by screw fixings, two of which 50, 52 can be seen in Figures 2 and 4.

The individual pairs of spigots connected to opposing pairs of lever arms are sized such that between them they extend across much of the gap between the input
10 and output lever arms. However, the pairs of spigots do not meet. In the positioner's natural, or rest, configuration (i.e. with no drive signal applied to the piezoelectric element), the spigots are separated by a distance that is approximately one-and-a-half times their expected range of travel during normal use of the positioner 2. This allows the positioner to cover its range of travel freely, but provides protection against
15 attempts to significantly exceed this range as this would cause the spigots to meet. Accordingly, the spigots act as mechanical stops or abutments. Other stop configurations are possible, though it is convenient to combine the stops with the spigot. Safety margins other than 50% are of course possible.

A sample mounted on the sample platform 6 may be moved to a desired
20 position along the z-direction by driving the piezoelectric element 8 to expand or contract. In its natural configuration (i.e. no drive signal applied) the positioner supports the sample at a position z_0 along the z-direction, this is referred to as its natural position or rest position. The z co-ordinate is taken to increase upwardly as indicated by the legend in Figure 1. To move the sample upwardly (i.e. increasing z)
25 from its natural position, a drive signal from a controller (not shown) is applied to the piezoelectric element such that it is driven to expand by an amount Δz^{pz} . The expansion of the piezoelectric element acts on the inner arms of the input and output levers such that the outer arms of opposing pairs of the input and output levers are brought together as the levers pivot about their respective flexible pivots. Because of
30 the arrangement of input and output flexible linkages, this causes the sample platform 6, and hence the sample supported on it, to move upwardly away from the base 4.

Although the motion of the individual lever arms is arcuate in the plane containing the z-axis of the piezoelectric element, the symmetric motion of the input and output lever arms causes the flexible linkage to move slightly diagonally. Accordingly, as the sample platform raises, in addition to moving relative to each other along the z-direction, the input and output flexible linkages also move inwardly towards the piezoelectric element by a small amount. Because of the symmetry of the positioner about a yz-plane running through the centre of the piezoelectric element, the flexible linkages on one side of the piezoelectric element move inwardly by an amount which is equal and opposite to that of the flexible linkages on the other side. Because of this, no net transverse motion is transferred to the sample platform relative to the base. The small transverse motions of the flexible linkages are accommodated by their flexible portions. Accordingly, the sample platform motion is largely decoupled from the horizontal components of motion associated with the arcuate movement of the outer arms of the levers on which the sample platform is supported. The sample platform therefore moves in a direction which is largely parallel to the z-axis. The amount by which the sample platform moves is determined by the amount by which the piezoelectric element expands and the mechanical advantage of the levers. For the example positioner shown in Figures 1 to 5, the effective length of the inner arms of the levers (i.e. the distance between their flexible pivots and the location at which the piezoelectric element acts on them) is one-third of the effective length of the outer arms of the levers (i.e. the distance between their flexible pivots and the flexible linkages). This means that as the piezoelectric element expands by an amount Δz^{pz} , the sample platform is raised by an amount $\Delta z^{sp} = 3\Delta z^{pz}$. Accordingly, the overall range of motion provided by the positioner is three times that of the piezoelectric element itself. Because of the symmetry of the positioner, this amplification is achieved while maintaining a substantially linear motion of the sample platform parallel to the drive axis of the piezoelectric element. It will be appreciated that other amplifications can be achieved by changing the ratio of the effective lengths of the inner and outer arms of the levers. It is even possible to provide a mechanical advantage of less than unity. Although this reduces the overall range of motion for the positioner, it effectively gears-down the expansion or

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contraction of the piezoelectric element. This can help to reduce jitter in the position of the sample platform associated with noise in the drive mechanism. For example, due to electronic noise in the drive signal applied to the piezoelectric element.

5 The sample can be moved further along the z-direction by further expanding the piezoelectric element or the sample can be moved back towards its natural position by contracting the piezoelectric element. It is possible to move the sample downwardly from its natural position by driving the piezoelectric element to contract from its natural configuration. However, a given piezoelectric element will generally allow for a larger range of expansion than it will for contraction. For example, a
10 piezoelectric element might typically be able to contract over a range which is only 10% or so of its expansion range. Accordingly the sample's natural position will typically be selected to correspond to be at or near the lowest position the sample will be required to adopt.

The instantaneous position of the sample platform can be calculated from the
15 positioner's known response to the drive signal applied to the piezoelectric element. Alternatively, it is possible to provide a sensor for making a measurement of the position. This reduces the impact of any long term drifts in the positioner response, and can also be used as a feed-back signal to assist positional stabilisation using a feedback loop.

20 The position measurement may come from the strain gauges 29a, 29b, 29c mounted to the piezoelectric element 8. Outputs from these strain gauges indicate the degree of expansion or contraction of the piezoelectric element 8. From this, the positions of the levers can be determined, and hence the position of the sample platform with respect to the base calculated. In one example, the strain gauges are
25 incorporated into Wheatstone bridge measurement circuitry mounted locally at the positioner. This reduces effects associated with, for example, thermal variations which might otherwise arise between different elements of the Wheatstone bridge.

In other examples, a more direct measure of the position of the sample platform relative to the base can be provided. For example, by having a linear
30 displacement transducer arranged to measure the overlap of neighbouring pairs of the input and output flexible linkages. In other cases, other feedback mechanisms may be

used, for example externally derived signals which depend on the position of a sample. For example, a reflection or interferometric optical encoder.

It will be appreciated that many other configurations of positioner are possible. For example, a single axis positioner that is not to be incorporated into a multi-axis
5 positioner, could employ rigid linkages in place of the flexible linkages for connecting the main body to the base and sample platform. In such cases, slide bearings or resilient bush mountings could be employed at both the base and sample platform fixings to accommodate any transverse motions associated with the arcuate motion of the lever outer arms.

10 In other examples, the input cross member may be solid such that it does not flex and is instead forms part of, or is rigidly connected to, the base. In such cases the expansion of the piezoelectric element acts wholly on the inner arms of the output levers (there being no input levers). This configuration causes the mounting dowels of the output flexible linkages to have an arcuate, rather than diagonal, motion. The
15 transverse motion component associated with this is again accommodated by the flexibility of the flexible linkages, or by the flexibility of the mountings in cases where rigid linkages are used.

The arrangement of having the input and output flexible linkages doubling-back on one another through the positioner allows relatively long linkages to be used
20 in a small space. This improves the flexibility of the linkages and also provides for a relatively large radius of curvature associated with any transverse motions. This reduces the coupling between the transverse and longitudinal motions of the positioner. However, in some embodiments the flexible linkages may not double back through the positioner, but may instead extend directly away from it. This effectively
25 reverses the direction of motion such that expansion of the piezoelectric element causes the sample platform to move in the opposite direction to that described above.

It will be appreciated that in some examples the output levers, and input levers where present, could be separate elements connected, for example by a leaf spring acting as a flexure hinge, and need not be formed from a single cross member having
30 a cut out to define a flexure hinge. In other examples, the output levers could be separate from one another with no flexure hinge or other direct link between them. In

these cases, load springs of the kind shown in Figures 1 to 4 can be used to replace the functionality of the flexible hinges (i.e. the function of providing load support and a restoring force). A link between the first and second support walls, or other means, could be used to hold the levers correctly in position relative to one another in such cases.

It will also be appreciated that other kinds of flexure pivot might be used as fulcrums for the levers. For example, in an example which does not include a unitary main body, support walls having an knife edges which sit in V-grooves in the levers may be used to provide the flexible pivots.

It will further be appreciated that piezoelectric element may be configured such that the axis of the piezoelectric element itself is not parallel to the drive axis along which it supplies the actuation, or drive, force. For example, the piezoelectric element may be arranged to expand and contract along one direction and a mechanical drive train configured transfer this motion so as to supply an actuation force along a drive axis.

As previously noted, the above has described a positioner for positioning a sample platform relative to a base along a vertical z-axis. It will be understood this particular orientation is arbitrary and the axis of the positioner can be arranged to position the sample platform relative to the base along any desired direction, including "up-side-down" configurations. References made above to upper, lower, upwardly, downwardly, and so forth, relate only to a positioner in the orientation shown in Figures 1 to 4.

Figure 6 schematically shows a perspective view of a positioner 102 according to a second embodiment of the invention. As before, the positioner 102 will be described with reference to a three-dimensional Cartesian co-ordinate system. A legend in the figure indicates the direction of the Cartesian co-ordinates.

The positioner 102 is a three-axis parallel positioner for moving a sample platform (or output stage) 106 relative to a base (or input stage) 104 along the x- y- and z-axes. The outer geometry of the positioner in this example is generally cuboid with a characteristic size of around 55 mm.

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Figure 7 schematically shows an exploded perspective view of the sample platform 106 and base 104. The base comprises three faces arranged to form three-faces of a cube. An xy-face 110 lies in an xy-plane, an xz-face 112 lies in an xz-plane and a yz-face 114 lies in a yz-plane. The sample platform similarly comprises three
5 faces arranged to form three-faces of a cube, again having an xy-face 120 lying in an xy-plane, an xz-face 122 lying in an xz-plane and a yz-face 124 lying in a yz-plane. In the assembled positioner 102 shown in Figure 6, the sample platform 106 and base 104 are located near to one another but are not in contact.

As can be seen from Figure 6, the three-axis positioner 102 comprises three
10 one-axis positioners connecting in parallel along three orthogonal axes between the sample platform 106 and the base 104. These three one-axis positioners are an x-axis positioner 2x, a y-axis positioner 2y and a z-axis positioner 2z. Each of these is similar, to and operates in the same way as, the positioner 2 described above and shown in Figures 1 to 5, except that the x-axis and y-axis positioners are differently
15 oriented.

The x-axis positioner 2x is arranged with its drive axis parallel to the x-axis and connects between the yz-face 114 of the base and the yz-face 124 of the sample platform. The mounting dowels for the input flexible linkages of the x-axis positioner 2x fit into holes 76, 78 in the yz-face 114 of the base. These dowels are held in place
20 by respective grub screws 90, 92. The mounting dowels for the output flexible linkages of the x-axis positioner 2x are similarly fixed into holes (not visible) in the yz-face 124 of the sample platform. Accordingly, when the x-axis positioner is driven as described above for the positioner 2 shown in Figures 1 to 5, the sample platform 106 is moved relative to the base 104 along the x-direction.

25 The y-axis positioner 2y is arranged with its drive axis parallel to the y-axis and connects between the xz-face 112 of the base and the xz-face 122 of the sample platform. The mounting dowels for the input flexible linkages of the y-axis positioner 2y fit into holes 72, 74 in the xz-face 112 of the base. These dowels are again held by grub screws. The mounting dowels for the output flexible linkages of the y-axis
30 positioner 2y are similarly fixed into holes 84, 86 in the xz-face 122 of the sample

platform. Accordingly, when the y-axis positioner is driven, the sample platform 106 is moved relative to the base 104 along the y-direction.

5 The z-axis positioner 2z is arranged with its drive axis parallel to the z-axis and connects between the xy-face 110 of the base and the xy-face 120 of the sample platform. The mounting dowels for the input flexible linkages of the z-axis positioner 2z fit into holes (not visible) in the xy-face 110 of the base. The mounting dowels for the output flexible linkages of the z-axis positioner 2z are fixed into holes 80, 82 in the xy-face 120 of the sample platform. Accordingly, when the z-axis positioner 2z is driven, the sample platform 106 is moved relative to the base 104 along the z-
10 direction.

Accordingly, the x-, y- and z-axis positioners may be driven to move and so position the sample platform along all three directions. Because the x-, y- and z-axis positioners each employ flexible linkages for connecting between the base and the sample platform, the positioners associated with each axis are able to accommodate
15 motion along each of the other axes in a manner broadly similar to that described in EP 0 937 961.

Returning to the one axis positioner 2 shown in Figure 2, in some examples the first and second support walls 18, 20 can be made sufficiently thin that they may be flexed outwardly or inwardly. This can be achieved using a suitably mounted
20 actuator. For example a piezoelectric element bonded to an outer face of one of the support walls may be driven to expand so flexing the support wall. One or more strain gauges may also be mounted on the support wall to measure the degree of flexure. Flexing the support wall on one side has the effect of bringing together the opposing pair of input and output levers on that side so as to increase the separation between the
25 base and the sample platform on the same side. Accordingly, flexing the support walls in this way can allow angular positioning of the sample platform shown in Figures 1 to 4 about the y-axis. Employing similar means for flexing the support walls in each of the three positioners shown in Figure 6 provides for a six-axis positioner.

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- [2] US 3 902 085 (Burleigh Instruments Inc.)
- 5 [3] Dieter Pohl, "Review of Scientific Instruments", vol. 58, p. 54-57 (1986).
- [4] JP 02 119277 (NEC Corp.)
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- [6] EP 0 937 961 (Melles Griot Ltd.)

CLAIMS

1. A positioner comprising:
a base and a sample platform moveable relative to the base;
5 a drive mechanism arranged to act between the base and the sample platform;
and
a plurality of levers extending away from each other, the levers supporting the
sample platform and being connected to the drive mechanism so that actuation of the
drive mechanism is transmitted under mechanical advantage of the levers to position
10 the sample platform.
2. A positioner according to claim 1, wherein each lever is rotatably mounted on
a fulcrum, thereby subdividing the levers into inner and outer arms with the inner
arms connected to the drive mechanism and the outer arms supporting the sample
15 platform.
3. A positioner according to claim 1 or 2, wherein the drive mechanism is
arranged to act on the levers in the same direction.
- 20 4. A positioner according any of claims 1 to 3, wherein the drive mechanism
comprises a piezoelectric element.
5. A positioner according to any of claims 1 to 4, wherein the plurality of levers
comprises at least one pair of levers that extend in opposite directions to each other.
25
6. A positioner according to any of claims 1 to 5, further comprising a flexible
hinge interconnecting at least some of the levers.
7. A positioner according to claim 6, wherein the levers are formed from a single
30 cross member, the flexible hinge being provided by a thinned section of the cross
member.

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8. A positioner according to any of claims 2 to 7, further comprising support walls that connect to the levers by flexible connections to form the fulcrums.
- 5 9. A positioner according to claim 8, wherein each lever and its support wall are of unitary construction, the flexible connection being provided by a thinned junction section.
- 10 10. A positioner according to any of claims 2 to 9, wherein the fulcrums are moveable relative to one another such that the sample platform may be rotated with respect to the base.
- 15 11. A positioner according to any of claims 1 to 10, wherein the sample platform is mounted on the levers by a pair of output linkages which are stiff in respect of forces applied along their axes of extent.
12. A positioner according to claim 11, wherein the output linkages are deformable in respect of forces applied transverse to their axes of extent.
- 20 13. A positioner according to claim 11 or 12, wherein the output linkages extend away from the levers on the same side as that on which the drive mechanism is located.
- 25 14. A positioner according to any of claims 11 to 13, wherein the output linkages extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.
- 30 15. A positioner according to any of claims 1 to 14, further comprising biasing elements connected to each lever and arranged to resist movement of the levers relative to the base and so provide a restoring force when the levers are moved.

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16. A positioner according to any of claims 1 to 15, further comprising a mechanical stop connected to each lever to limit the amount by which it can move relative to the base.
- 5 17. A positioner according to any of claims 1 to 16, wherein the mechanical advantage of the levers acts to move the sample platform by an amount which is more than the movement of the drive mechanism.
- 10 18. A positioner according to any of claims 1 to 16, wherein the mechanical advantage of the levers acts to move the sample platform by an amount which is less than the movement of the drive mechanism.
- 15 19. A positioner according to any of claims 1 to 18, further comprising one or more strain gauges for measuring the positions of the levers.
- 20 20. A positioner according to claim 19, wherein the one or more strain gauges are coupled to respective bridge measuring circuits mounted on the positioner.
- 20 21. A positioner according to any of claims 1 to 20, comprising a further plurality of levers extending away from each other, the further levers being connected to the base and the drive mechanism so that actuation of the drive mechanism is transmitted to the further levers to cause them to move with respect to the base.
- 25 22. A positioner according to claim 21, each further lever being rotatably mounted on a fulcrum, thereby subdividing the further levers into inner and outer arms with the inner arms connected to the drive mechanism and the outer arms connected to the base.
- 30 23. A positioner according to claim 21 or 22, the drive mechanism being arranged to act on each of the further levers in the same direction.

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24. A positioner according to any of claims 21 to 23, the drive mechanism being arranged to act on the further levers in a direction which is different to that in which it acts on the first mentioned levers.
- 5 25. A positioner according to any of claims 21 to 24, each of the further levers being aligned with a corresponding one of the first mentioned levers.
26. A positioner according to any of claims 21 to 25, the further levers being connected together by a flexible hinge.
- 10 27. A positioner according to claim 26, wherein the further levers are formed from a single cross member, the flexible hinge being provided by a thinned section of the cross member.
- 15 28. A positioner according to any of claims 22 to 27 when dependent on claim 8, the support walls also supporting the further levers, the further levers being connected to the support walls by flexible connections for providing the fulcrums.
- 20 29. A positioner according to claim 28, wherein each further lever and its support wall are of unitary construction, the flexible connection being provided by a thinned section at their junction.
30. A positioner according to claim 28 or 29, wherein the first mentioned, levers, the support walls and the further levers are of unitary construction.
- 25 31. A positioner according to any of claims 21 to 30, wherein the further levers are connected to the base by a pair of input linkages which are stiff in respect of forces applied along their axes of extent.
- 30 32. A positioner according to claim 31, wherein the input linkages are deformable in respect of forces applied transverse to their axes of extent.

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33. A positioner according to claim 31 or 32, wherein the input linkages extend away from the input levers on the same side as that on which the drive mechanism is located.

5

34. A positioner according to any of claims 31 to 33, wherein the input linkages extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.

10 35. A positioner according to any of claims 21 to 34, further comprising biasing elements connected to each further lever and arranged to resist movement of the further levers relative to the base and so provide a restoring force when the further levers are moved.

15 36. A positioner according to any of claims 21 to 35, further comprising a mechanical stop connected to each further lever to limit the amount by which it can move relative to the base.

20 37. A positioner according to any of claims 21 to 36, further comprising one or more strain gauges for measuring the positions of the further levers.

38. A positioner according to claim 37, wherein the one or more strain gauges are coupled to respective bridge measuring circuits mounted on the positioner.

25 39. A multi-axis positioner comprising a first positioner according to any of claims 1 to 38 aligned along a first direction and a second positioner according to any of claims 1 to 38 aligned along a second, different, direction, the first and second positioners connecting between a common base and a common sample platform.

30 40. A multi-axis positioner according to claim 39, wherein the first direction and the second direction are orthogonal to one another.

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41. A multi-axis positioner according to claim 39 or 40, further comprising a third positioner according to any of claims 1 to 38 aligned along a third direction, the third direction being different to the first and second directions, the third positioner
5 connecting between the common base and the common sample platform.

42. A multi-axis positioner according to claim 41, wherein the third direction is orthogonally arranged with respect to at least one of the first or second directions.

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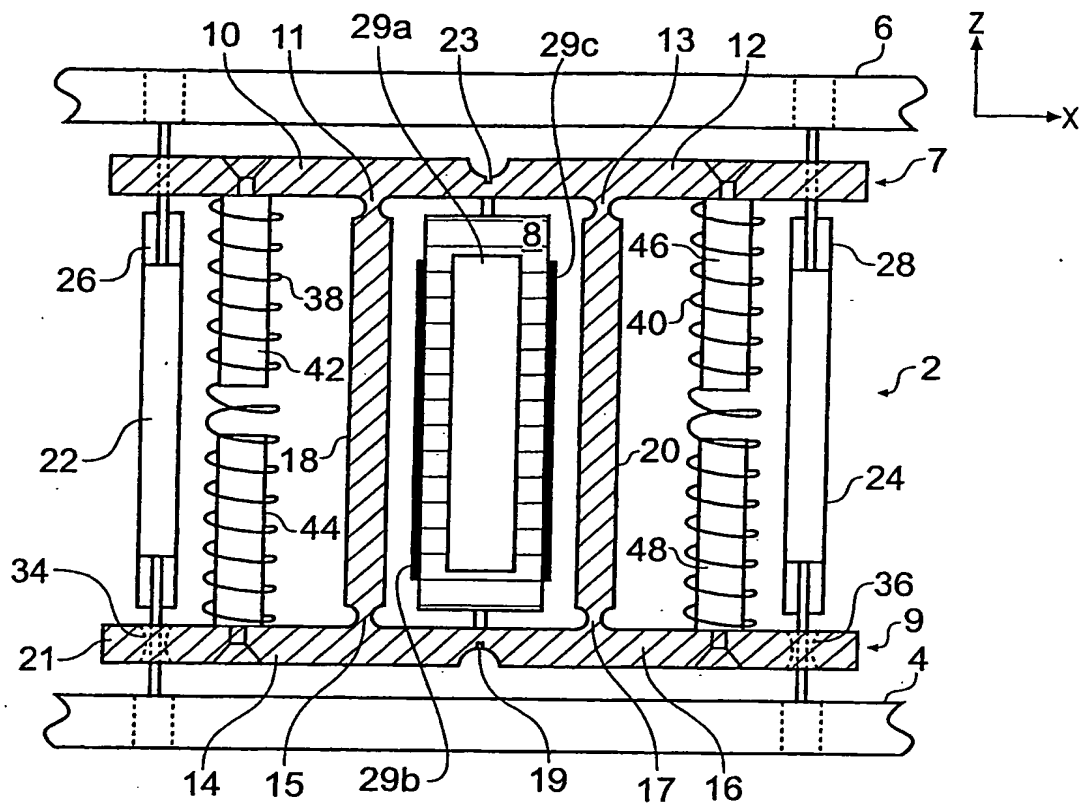


Fig. 1

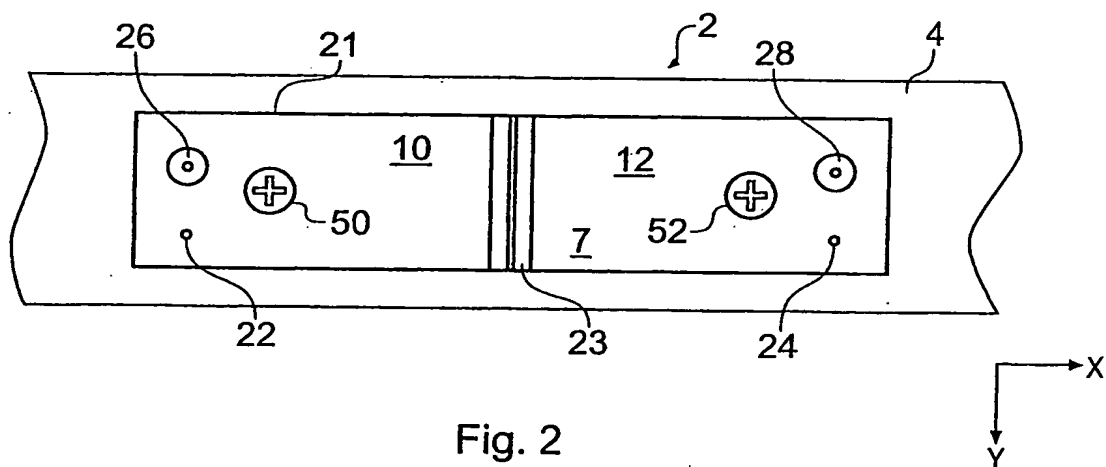


Fig. 2

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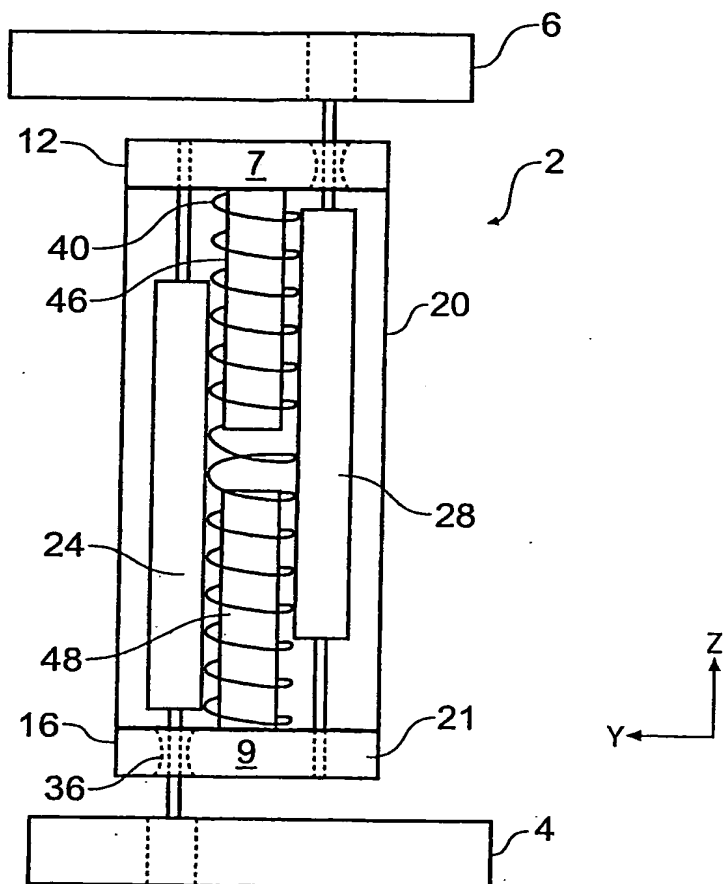


Fig. 3

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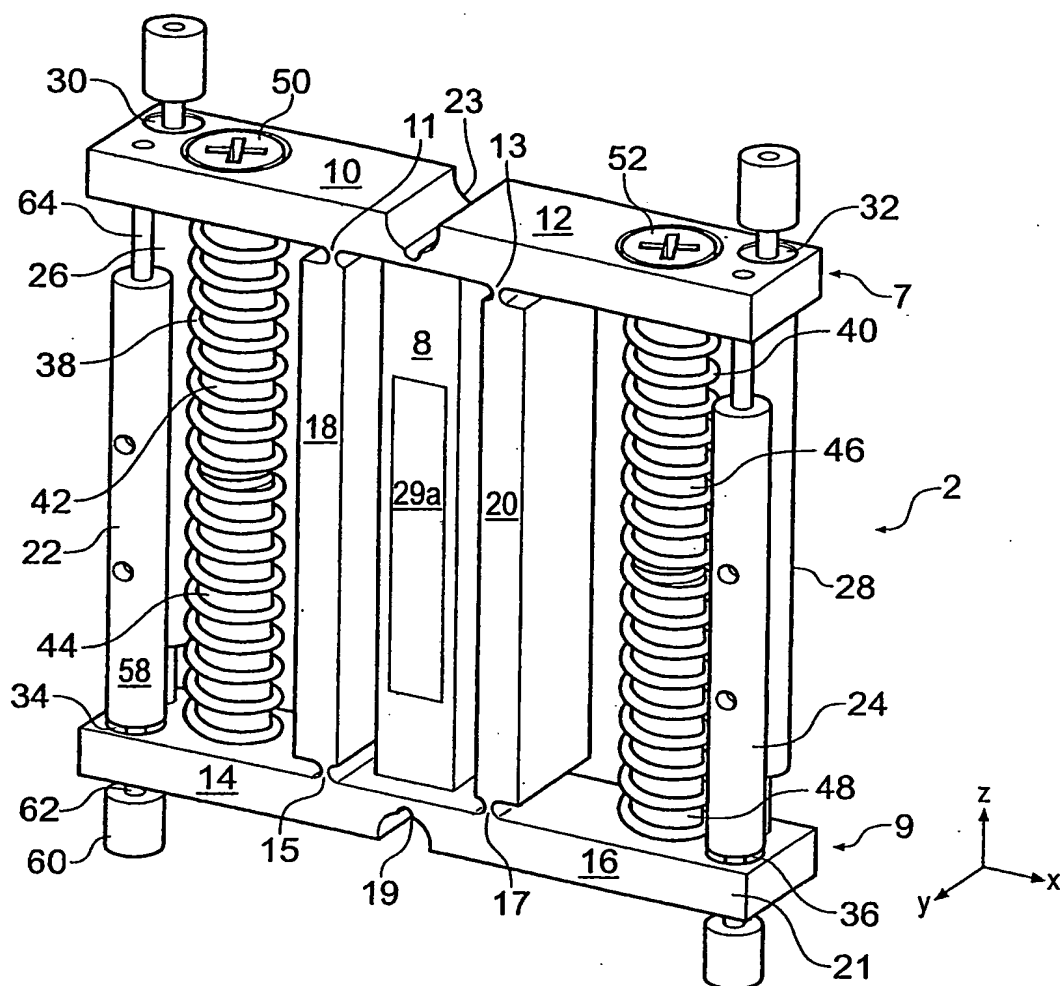


Fig. 4

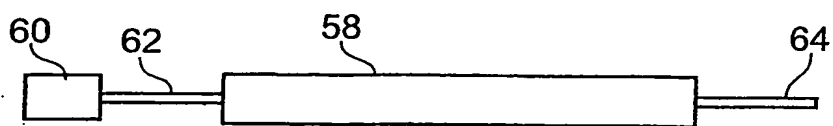


Fig. 5

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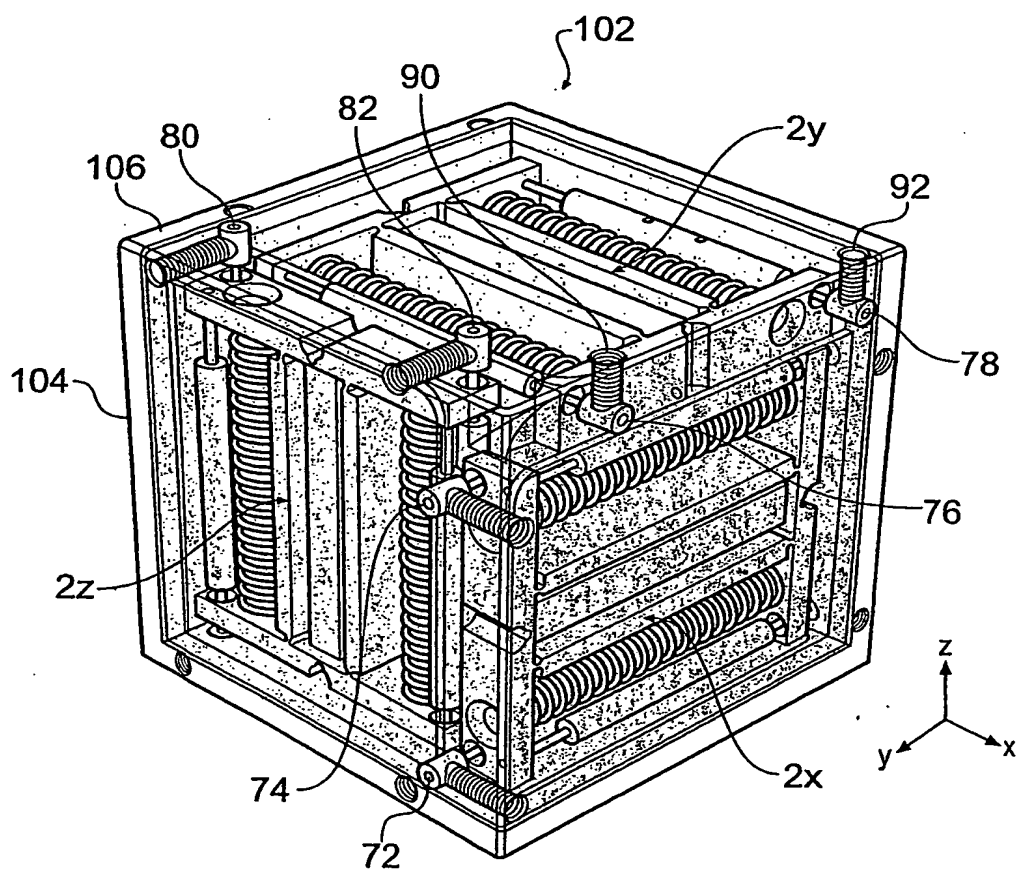


Fig. 6

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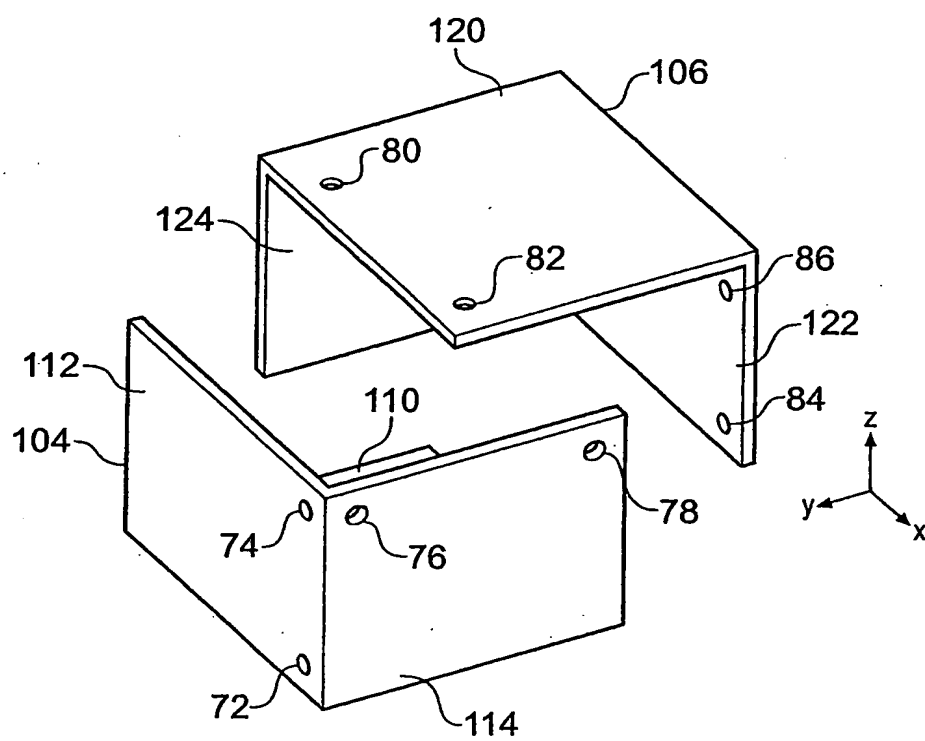


Fig. 7



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Via Registered Mail

U.S. Patent Application No.: 10/589,684
Title: Positioner Device
Inventors: Terence J. HERBERT and Michael J. DIXON
Our Reference: 09314.0046

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Dear Mr. Herbert:

Enclosed is a Declaration under 37 C.F.R. § 1.131 and an Assignment corresponding to the United States patent application that was filed in the U.S. Patent and Trademark Office on August 16, 2006, for "Positioner Device." A copy of this application is also included for your reference.

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3300 Hillview Ave.
Palo Alto, CA 94304

If you have any questions, please contact me.

Sincerely,

Gary J. Edwards

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Via Registered Mail

U.S. Patent Application No.: 10/589,684
Title: Positioner Device
Inventors: Terence J. HERBERT and Michael J. DIXON
Our Reference: 09314.0046

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A handwritten signature in dark ink, appearing to read 'Gary J. Edwards', written over a horizontal line.

Gary J. Edwards

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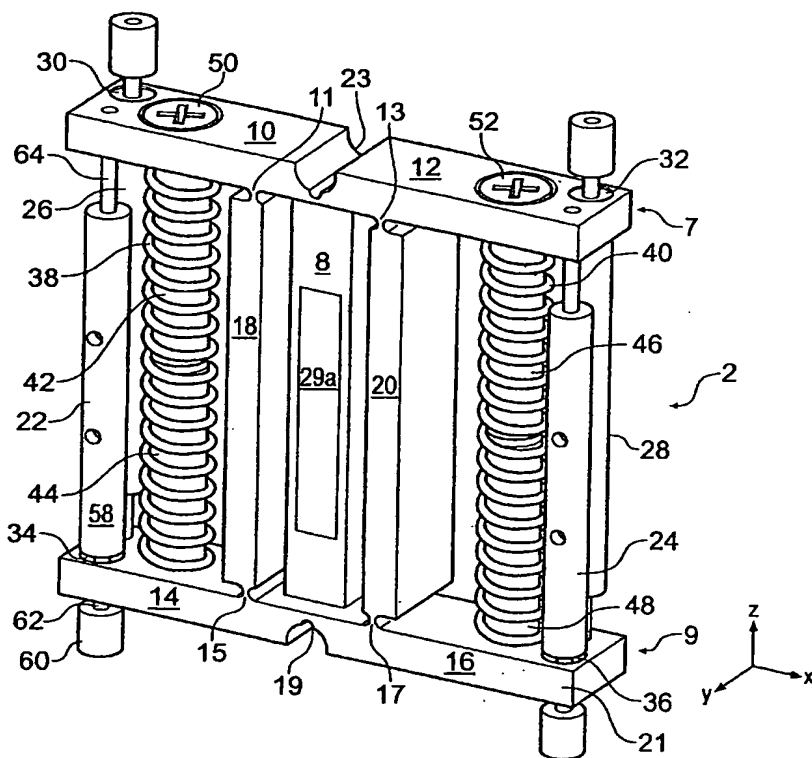
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(54) Title: **POSITIONER DEVICE**



(57) Abstract: A positioner (2) for moving a sample platform (6) relative to a base (4) is described. The positioner is driven by a piezoelectric arranged to expand and contract along a drive axis, the piezoelectric element has an input end coupled to the base and an output end coupled to first (14) and second (16) output levers extending away from the drive axis of the piezoelectric element in opposing directions. The output levers each have an inner arm arranged to be acted on by the piezoelectric element as it expands and an outer arm to which the sample platform is mounted via platform supports (26, 28). The output levers are mounted such that the piezoelectric element acts on the inner arms of the output levers to cause the outer arms to move in a plane containing the drive axis. This motion of the output levers is communicated via the platform supports to the sample platform, so moving it relative to the base along a direction parallel to the drive axis.

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POSITIONER DEVICE

BACKGROUND OF THE INVENTION

5 The invention relates to positioners which are widely used for a variety of applications including the positioning of optical components, both in production lines and in scientific experiments.

One shortcoming of positioners designed to provide a high degree of accuracy in their positioning is that they are often only able to operate over a relatively limited range. For example, a number of positioner designs employ piezoelectric drive elements in their drive mechanisms. Piezoelectric drive elements are useful because
10 they are relatively robust and are able to provide repeatable high precision positioning. However, a 38 mm long piezoelectric stack might have a positioning range of only 42 μm . This limited range can mean positioners employing piezoelectric drive elements can be impractical for many applications. Similar problems can arise with other types
15 of high precision drive mechanisms.

US 3 902 084 [1] and US 3 902 085 [2] describe "inchworm positioners" which address this problem. These are one-axis positioners arranged to selectively grip and release opposing ends of a piezoelectric drive element as it is cyclically expanded and contracted. Appropriate control of the piezoelectric drive element and
20 the piezoelectric grips at either end can cause the piezoelectric drive element to inch its way along between the grips during successive expand and contract cycles. Although positioners of this type allow for larger ranges of motion, they are complex designs requiring a number of moving parts which must be separately controlled in a carefully orchestrated manner.

25 Another approach is to use a positioner comprising two elements in frictional engagement with one another which slide relative to one another when the frictional force between them is overcome. Motion is generated by the interplay between inertia of one of the elements and slipping or sticking of the frictional engagement between the elements. Positioners of this kind are referred to as inertial positioners or slip-stick

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positioners and are known for example from an article by Dieter Pohl in the journal "Review of Scientific Instruments" [3]. Inertial slip-stick positioners can be made with relatively few major components. However, known inertial slip-stick positioners have a low load bearing capacity and a high degree of sensitivity to orientation, unlike the above described inchworm positioners.

An alternative solution would be to use a lever arrangement to magnify or amplify the motion. JP 02 119277 [4] describes a mechanical amplifier for a piezoelectric drive element, albeit one designed primarily for dot-matrix printer heads. The device of JP 02 119277 employs a pair of hinged levers mounted at opposing ends of a piezoelectric stack such that the lever's outer arms are brought together as their inner arms are pushed apart by the piezoelectric element expanding. A buckle spring connects between the lever's outer arms and buckles outwardly as the lever arms are brought together. The outward motion of the buckle spring provides the useful output of the device. EP 0 510 698 [5] employs principles similar to those of JP 02 119277, but has two buckle springs connected in series between the levers. This provides for two simultaneous displacement outputs. Devices of this kind are not generally suitable for the reliable positioning of sample platforms. This is because their sprung nature makes them prone to vibration, and their buckling movement will generally be different for different platform loads. This means samples having different masses will generally be positioned differently for the same expansion of the piezoelectric drive element.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a positioner comprising: a base and a sample platform moveable relative to the base; a drive
5 mechanism arranged to act between the base and the sample platform; and a plurality of levers extending away from each other, the levers supporting the sample platform and being connected to the drive mechanism so that actuation of the drive mechanism is transmitted under mechanical advantage of the levers to position the sample platform.

10 The use of levers allows the motion of the drive mechanism, for example the expansion or contraction of a piezoelectric element, to be amplified before being transmitted to the sample platform. Furthermore, by mounting the sample platform on a plurality of levers extending away from each other, a stable mounting can be achieved which is resistant to torque forces applied by the weight of a sample on the
15 sample platform, for example where the sample is located off-centre. In addition, the use of a plurality of levers allows the arcuate motions associated with each of the individual levers to be combined to provide a linear motion of the sample platform.

Throughout the following, the levers will sometimes be referred to as output levers. This term reflects that they support the sample platform, which may be
20 considered an output stage of the positioner.

Each lever can be rotatably mounted on a fulcrum which subdivides the levers into inner and outer arms with the inner arms being connected to the drive mechanism and the outer arms supporting the sample platform.

This allows for simple lever and drive mechanism configurations. However, it
25 will be appreciated that other configuration are possible. For example, the sample platform and drive mechanism may both be coupled to the output arms, the relative locations of their couplings determining the mechanical advantage.

The drive mechanism may be arranged to act on each of the levers in the same direction such that they move in a similar manner to one another when the drive
30 mechanism is actuated.

The plurality of levers may comprise two levers extending in opposing directions.

The levers may be connected to one another by a flexible hinge. The flexible hinge may be a leaf spring connecting between the levers, for example, or the levers
5 may be formed from a single cross member. The flexible hinge being provided by a thinned section of the cross member.

Connecting the levers in this way provides a restoring force as each of the levers are pivoted about their fulcrums, sometimes referred to as flexible pivots, away from their rest positions. This restoring force provides a support force for the sample
10 platform. By forming the levers from a single cross member, a structurally robust and easy to assemble configuration having a low number of parts can be provided.

Support walls may be used for pivotably supporting the levers at their fulcrums, the levers being connected to the support walls by flexible connections providing the fulcrums which allow them to pivot. Furthermore, each lever and its
15 support wall may be of unitary construction with the flexible connections being provided by thinned sections at the junctions between the levers and support walls.

This kind of flexible pivot provides a further restoring force as each of the levers are pivoted, so increasing the support force for the sample platform. The unitary construction is structurally robust and easy to assemble having a low number of parts.

20 The support walls providing the flexible pivot support may be configured to be independently flexed. For example, a piezoelectric transducer may be bonded to a face of one of support walls which can be driven to expand, so causing the support wall to flex. Flexing one or other (or both) support walls reduces their effective length relative to one another. This can cause relative movement between the fulcrums of the
25 different levers. Because the sample platform is connected to each of the levers, this relative movement between the fulcrums leads to a rotation of the sample platform with respect to the base, so allowing for angular positioning.

The sample platform may be mounted on the levers by a pair of output linkages which are stiff in respect of forces applied parallel to their axes of extent.
30 This allows motion to be reliably transferred from the levers to the sample platform.

The output linkages may be deformable in respect of forces applied transverse to their axes of extent. This assists the positioner to accommodate the transverse components of the arcuate motion of the levers and so provide the linear motion of the sample platform. In other cases, resilient mountings between the output linkages and the levers and/or the sample platform may be provided to accommodate these transverse motion components.

The flexible output linkages allow the positioner to reliably position the sample platform parallel to the drive axis, even if the sample platform is being moved or is offset relative to the base in a direction which is transverse to the drive axis, the transverse movement being accommodated by flexure of the output linkages. This allows a number of the positioners to be connected in parallel in a multi-axis positioner. For example, two or three orthogonally mounted positioners may be connected between a common base and a common sample platform to provide a two- or three-axis positioner.

The output linkages may extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.

The output linkages may extend away from the levers on the same side as that on which the drive mechanism, or a significant part of it, is located.

This "doubling-back" of the output linkages allows the use of relatively long output linkages in a small space. The use of long output linkages improves their flexibility. In addition, long output linkages provide for a relatively large radius of curvature for the transverse motions associated with either the arcuate motion of the levers, or the transverse motion of the sample platform relative to the base in a multi-axis positioner. Having a large radius of curvature acts to reduce the coupling between the transverse and longitudinal components of the motion of the positioner.

The positioner may further comprise biasing elements, for example springs, e.g. helical springs, connected to each lever and arranged to resist movement of the levers relative to the base. The biasing acts to provide an additional restoring force for the levers as they are moved by the drive mechanism. This further increases the load which the positioner can reliably support and position.

The positioner may further comprise a stop mechanism connected to each lever to limit the amount by which it can move relative to the base. This helps to prevent the positioner from being damaged, for example by being overloaded or over driven by the drive mechanism.

5 In general, the geometry of the levers and the locations at which the sample platform and the drive mechanism are coupled to them, will be such that the sample platform moves by an amount greater than an amount by which the drive mechanism moves. That is to say the mechanical advantage, or mechanical amplification, of the lever's action will be greater than unity. However, in some examples the arrangement
10 will be such the sample platform moves by an amount less than an amount by which the drive mechanism moves. That is to say the mechanical advantage, or mechanical amplification, of the lever's action will be less than unity. This arrangement effectively gears-down the expansion or contraction of the piezoelectric element. This allows a sample to be positioned more accurately than the drive mechanism precision.

15 The positioner may include one or more strain gauges for measuring the position of the levers. There are a number of points at which strain gauges may be mounted. For example, strain gauges may be coupled to the parts drive mechanism. For example, they may be bonded to the side of a piezoelectric element which might form part of the drive mechanism. This allows the movement of the drive mechanism
20 to be measured, from which the positions of the levers can be calculated. From the positions of the levers, the position of the sample platform relative to the base can be determined. Strain gauge output signals can also be used in a feed back control loop to improve the positioning stability, i.e. to provide an encoder device.

 The one or more strain gauges may be coupled to respective bridge measuring
25 circuits. For example, Wheatstone bridge measuring circuits, which are mounted on the positioner itself. This can help to reduce effects arising from temperature differentials between different elements of the bridge circuitry. In some embodiments, a strain gauge may be used in each arm of the bridge circuitry to provide increased sensitivity.

30 The positioner may include a further plurality of levers extending away from each other, the further levers being connected to the base and the drive mechanism so

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that actuation of the drive mechanism is transmitted to the further levers to cause them to move with respect to the base.

Each further lever may be rotatably mounted on a fulcrum, thereby subdividing the further levers into inner and outer arms with the inner arms connected
5 to the drive mechanism and the outer arms connected to the base.

The further levers may be arranged such that the drive mechanism acts on each of the further levers in the same direction. This may be a direction which is different to that in which the drive mechanism acts on the first mentioned, or output, levers.

Throughout the following, the further levers will sometimes be referred to as
10 input levers. This term reflects that they are coupled to the base, which may be considered an input stage of the positioner.

The input levers generally mirror the output levers and so provide a positioner with a high degree of symmetry. It will be understood that the design and construction of the input levers may include a number of features which correspond to those
15 described above for the output levers.

A pair of input linkages may be used for connecting the base to the input levers, the input linkages being stiff in respect of forces applied parallel to their axes of extent but deformable in respect of forces applied transverse thereto. The input linkages may again be doubled-back, i.e. extending away from the input levers on the
20 same side as that on which the drive mechanism is located, to allow for long linkages in a small space.

By providing a highly symmetric design such as this, movement of the drive mechanism can be transferred to the sample platform via a combined motion of the output and input levers. This means the output levers only need pivot by
25 approximately half the amount they would otherwise do if there were no input levers to accommodate part of the motion of the drive mechanism. This reduces residual effects associated with the arcuate motion of the levers.

The highly symmetric design additionally reduces the number of different component parts of the positioner, so providing for more simple manufacture.

30 According to a second aspect of the invention there is provided a multi-axis positioner comprising a first positioner according to the first aspect of the invention

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aligned along a first direction and a second positioner according to the first aspect of the invention aligned along a second, different, direction, the first and second positioners connecting between a common base and a common sample platform.

5 The multi axis-positioner may further comprise a third positioner according to the first aspect of the invention aligned along a third direction, the third direction being different to the first and second directions, the third positioner connecting between the common base and the common sample platform.

10 In this way, a multi-axis positioner having a parallel mechanism may be provided having up to six degrees of freedom. Where six degrees of freedom are not required, fewer may be provided. For example, the third positioner might not provide for rotation of the sample platform, such that a five-axis positioner is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention and to show how the same may be carried into effect reference is now made by way of example to the accompanying
5 drawings in which:

Figure 1 schematically shows a front view of a one-axis positioner according to a first embodiment of the invention;

Figure 2 schematically shows an end view of the positioner shown in Figure 1;

Figure 3 schematically shows a side view of the positioner shown in Figure 1;

10 Figure 4 schematically shows a perspective view of the positioner shown in Figure 1;

Figure 5 schematically shows a flexible linkage of the positioner shown in Figure 1;

15 Figure 6 schematically shows a perspective view of a three-axis positioner according to a second embodiment of the invention; and

Figure 7 schematically shows an exploded perspective view of a base and a sample platform for the positioner shown in Figure 6.

DETAILED DESCRIPTION

Figures 1, 2, 3 and 4 schematically show respective front, end, side and perspective views of a positioner 2 according to a first embodiment of the invention.

- 5 The positioner 2 is described with reference to a three-dimensional Cartesian coordinate system and terms such as upper and lower refer to the orientation shown in Figure 1. It will be appreciated, however, that the positioner can be equally be used in other orientations. The front view of Figure 1 is taken along a y-axis, the end view of Figure 2 is taken along a z-axis and the side view of Figure 3 is taken along an x-axis.
- 10 A legend in each figure indicates the Cartesian plane of the figure.

The positioner 2 is a one-axis positioner for moving a sample platform (or output stage) 6 relative to a base (or input stage) 4 along the z-axis. (The sample platform 6 is not shown in Figures 2 or 4 and the base 4 is also not shown in Figure 4). The positioner in this example has a characteristic size of around 55 mm in the x- and z-directions and about 15 mm in the y-direction. However, it is noted the design is inherently scalable so these dimensions could be much smaller or larger if desired. In fact, the design could be useful for a micro-electromechanical system (MEMS) or nano-technology environment implemented in semiconductor materials using etch technology. The positioner comprises a main body member 21 made of stainless steel,

15 a piezoelectric element 8, a pair of input flexible linkages 22, 24 connecting the main body 21 to the base 4, a pair of output flexible linkages 26, 28 connecting the main body 21 to the sample platform 4, load springs 38, 40 and mounting spigots 42, 44, 46, 48 for the load springs. The piezoelectric element 8 is schematically illustrated as a stack, but it will be understood that a tube or other form of piezoelectric element

20 could be used. Other kinds of actuator, such as a driven screw, may also be used.

In this example, the main body 21 is of unitary construction and comprises an input cross member 7 to which the input flexible linkages 22, 24 are attached and an output cross member 9 to which the output flexible linkages 26, 28 are attached. The input and output cross members 7, 9 are separated from one another by first and second support walls 18, 20. The input cross member 7 has a cut-out in its upper face running parallel to the y-axis. This provides for an input flexure hinge 23 which

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allows the input cross member to flex at its centre. The output cross member 9 has a similar cut-out in its lower face. This provides for an output flexure hinge 19 which allows the output cross member to flex at its centre. The connections between the respective ends of the first and second support walls 18, 20 and the input and output
5 cross members 7, 9 comprise thinned sections of the main body 21 extend along the y-direction so as to provide respective flexure pivots 11, 13, 15, 17 which act as fulcrums.

The combination of flexure hinges 23, 19 in the cross members 7, 9 and the flexure pivots 11, 13, 15, 17 provide for four levers 10, 12, 14, 16. The input cross
10 member 7 is divided by its flexure hinge 23 into a first input lever 10 and a second input lever 12 with respective ones of the flexible pivots 11, 13 providing fulcrums for each of the input levers. The output cross member 9 is divided by its flexure hinge 19 into a first output lever 10 and a second output lever 12 with respective ones of the flexible pivots 15, 17 providing fulcrums for each of the output levers. Accordingly,
15 the input and output levers to one side of the piezoelectric element 8 form a first opposing pair of input and output levers 10, 14 while the input and output levers to the other side of the piezoelectric element 8 form a second opposing pair of input and output levers 12, 16. Each lever 10, 12, 14, 16 is subdivided by its respective flexible pivot 11, 13, 15, 17 into an inner arm and an outer arm. The inner arms of the levers
20 are those parts extending inwardly from the flexible pivots towards the flexure hinges. The outer arms are those parts of the levers extending outwardly away from the flexure hinges.

The piezoelectric element 8 extends between the input and output cross members 7, 9 and is positioned between the support walls 18, 20. The piezoelectric
25 element is arranged so as to expand and contract along the z-axis when driven by an appropriate drive signal. The piezoelectric element has an input end adjacent the input cross member 7 and an output end adjacent the output cross member 8. The interfaces between the ends of the piezoelectric element 8 and the cross members 7, 9 are arranged such that the cross members may flex at their flexure hinges without
30 damaging the piezoelectric element. This can be achieved, for example, by employing a bearing pad having a limited contact area aligned with the flexure hinges of the cross

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members. The piezoelectric element 8 is dimensioned slightly longer than the gap into which it is to be placed. The piezoelectric element is inserted into this undersized gap by first forcing the outer arms of opposing pairs of the input and output levers together. This causes the levers 10, 12, 14, 16 to pivot about their respective flexure pivots 11, 13, 15, 17 such that the gap into which the piezoelectric element is fitted is increased, and the piezoelectric element can be inserted. Once the piezoelectric element is in place, the force applied to the outer arms of the levers is removed so that the main body attempts to re-adopt its unstressed configuration. However, it is prevented from doing so fully by the additional length of the piezoelectric element. This ensures the piezoelectric element is kept under compression. This pre-stressing of the piezoelectric element improves its operating characteristics, as is well known.

A strain gauge is bonded to each side of the piezoelectric element. Three of the strain gauges 29a, 29b, 29c can be seen in Figure 1. Each strain gauge is configured to measure the degree of expansion or contraction of the piezoelectric element 8. It will be appreciated that the expansion or contraction of the piezoelectric element 8 could be measured using other strain gauge configurations. For example, only one strain gauge might be used. However, multiple strain gauges can provide improved sensitivity.

Figure 5 is a schematic cross-section view of one of the input flexible linkages 22 used to connect the input cross member 7 to the base 4. The other flexure linkages 24, 26, 28 are identical in structure to the flexure linkage 22 shown in Figure 5, although are differently installed in the positioner 2. The linkage is rigid in respect of forces applied along its axis of extent, but flexible in respect of transversely applied forces. It will be appreciated that in some single axis embodiments of the invention, the flexible linkages 22, 24, 26, 28 could be replaced with rigid linkages which are not deformable in respect of transversely applied forces. However, as will be seen further below, flexible linkages of the kind shown in Figure 5 allow for a positioner which can be easily integrated into a multi-axis positioner. The flexure linkage 22 contains a rigid central body 58 with a mounting dowel 60 attached to one end by a flexible portion 62. A similar flexible portion 64 extends from the other end of the central body but terminates freely. The central body and mounting dowel are made of 3 mm

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diameter stainless steel rod. The flexible portions are made of 1 mm diameter music wire. The mounting dowel is around 5 mm long and the central body is around 25 mm long. The music wire is received into bores in the central body and the mounting dowel such that approximately 10 mm is left exposed between the central body and the mounting dowel and around 15 mm is left exposed on the other side. The flexible linkage 22 has an overall length of around 55 mm. Because the sections of music wire are relatively short, the flexible linkage has a relatively high longitudinal stiffness but is free to flex in the transverse direction. Linkages of this kind are further described in EP 0 937 961 [6].

10 As can be seen from Figure 4, input flexible linkage 22 is installed in the positioner 2 such that the free-end flexible portion 64 is fixedly connected near the edge of the outer arm of input lever 10. The linkage then extends substantially parallel to the z-axis towards output lever 14, the central body 58 being disposed between the opposing lever arms 10, 14. The flexible portion 62 to which the mounting dowel is
15 attached passes through a rubber bushing 34 in the output lever 14. The rubber bushing 34 allows the input flexible linkage 22 to slide freely in a direction parallel to its axis of extent, but not transversely to this axis. A degree of damping is provided by the rubber bushing and this helps to reduce vibrational noise in the positioner. With the positioner 2 in the orientation shown in Figure 4, the mounting dowel 60 is located
20 beneath the output lever 14. As mentioned above, the base 4 is not shown in Figure 4. However, as can be seen from Figure 1, the mounting dowel 60 is received into an opening in the base where it is held in place, for example by gluing or using grub screws.

The other flexible input linkage 24 is installed in a similar fashion, connecting
25 between the input lever 12 and output lever 14, and passing through rubber bushing 36. The mounting dowel of flexible linkage 24 is similarly attached to the base 4. Accordingly, the positioner 2 is supported with respect to the base 4 by the two input flexible linkages. Because the input flexible linkages are longitudinally rigid, the parts of the outer arms of the input levers to which the input flexible linkages attach are
30 fixed relative to the base along the z-direction. However, because of their flexibility to transverse forces, the parts of the outer arms of the input levers to which the input

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flexible linkages attach may be moved in the x- and y-directions. It will be appreciated that this motion will be arcuate in the xz- and yz-planes respectively, but for ease of explanation, they are described by the direction of their largest component.

The output flexible linkages 26, 28 are installed in an overall similar fashion to the input flexible linkages 22, 24, but, rather than connecting the base to the input levers, they connect the output levers to the sample platform. That is to say, the free end flexible portions of the output flexible linkages are fixedly connected near the edge of the outer arms of respective ones of the output levers 14, 16. The linkages then extend substantially parallel to the z-axis towards input levers 10, 12. For the orientation shown in Figure 4, the mounting dowels of the output flexible linkages are located above the input levers 10, 12. The sample platform 6 is not shown in Figure 4. However, as can be seen from Figure 1, the mounting dowels of the output flexible linkages are received into openings in the sample platform where they are held in place.

Accordingly, the sample platform 6 is supported relative to the base along the z-axis via the output flexible linkages which connect it to the main body 21 which in turn is supported by the input flexible linkages which connect it to the base. The Sample platform is free to move in the x- and y-directions. If this is not desired, support rails or other bracing could be used.

For a positioner in the orientation shown in Figures 1 to 4, the weight of a sample on the sample platform applies a load force which is transmitted from the sample platform 6 along the output flexure linkages 26, 28 so as to act downwardly on the outer arms of the output levers 14, 16. The reaction force supporting the weight of the sample is transmitted from the base 4 along the input flexure linkages 22, 24 so as to act upwardly on the outer arms of the input levers 10, 12. The net effect of this is that opposing pairs of input and output levers are urged apart. This motion is resisted by the resilience of the flexure hinges 17 and 19, the resilience of the flexure pivots 11, 13, 15, 17 and the resistance to compression of the piezoelectric element 8. To increase the useful load that the positioner can support without damaging the flexure hinges, flexure pivot or the piezoelectric element 8 and to provide a positive force against displacements, load springs 38, 40 are used. These connect between the outer

arms of each opposing pair of input and output levers to provide additional support for the sample platform by effectively increasing the rigidity main body 21. One of the load springs 38 is mounted on a pair of spigots 42, 44 respectively connected to one opposing pair of input and output levers 10, 14. The other load spring 40 is mounted
5 on a similar pair of spigots 46, 48 connected to the other opposing pair of input and output levers 12, 16. The spigots are held in place by screw fixings, two of which 50, 52 can be seen in Figures 2 and 4.

The individual pairs of spigots connected to opposing pairs of lever arms are sized such that between them they extend across much of the gap between the input
10 and output lever arms. However, the pairs of spigots do not meet. In the positioner's natural, or rest, configuration (i.e. with no drive signal applied to the piezoelectric element), the spigots are separated by a distance that is approximately one-and-a-half times their expected range of travel during normal use of the positioner 2. This allows the positioner to cover its range of travel freely, but provides protection against
15 attempts to significantly exceed this range as this would cause the spigots to meet. Accordingly, the spigots act as mechanical stops or abutments. Other stop configurations are possible, though it is convenient to combine the stops with the spigot. Safety margins other than 50% are of course possible.

A sample mounted on the sample platform 6 may be moved to a desired
20 position along the z-direction by driving the piezoelectric element 8 to expand or contract. In its natural configuration (i.e. no drive signal applied) the positioner supports the sample at a position z_0 along the z-direction, this is referred to as its natural position or rest position. The z co-ordinate is taken to increase upwardly as indicated by the legend in Figure 1. To move the sample upwardly (i.e. increasing z)
25 from its natural position, a drive signal from a controller (not shown) is applied to the piezoelectric element such that it is driven to expand by an amount Δz^{pz} . The expansion of the piezoelectric element acts on the inner arms of the input and output levers such that the outer arms of opposing pairs of the input and output levers are brought together as the levers pivot about their respective flexible pivots. Because of
30 the arrangement of input and output flexible linkages, this causes the sample platform 6, and hence the sample supported on it, to move upwardly away from the base 4.

Although the motion of the individual lever arms is arcuate in the plane containing the z-axis of the piezoelectric element, the symmetric motion of the input and output lever arms causes the flexible linkage to move slightly diagonally. Accordingly, as the sample platform raises, in addition to moving relative to each other along the z-direction, the input and output flexible linkages also move inwardly towards the piezoelectric element by a small amount. Because of the symmetry of the positioner about a yz-plane running through the centre of the piezoelectric element, the flexible linkages on one side of the piezoelectric element move inwardly by an amount which is equal and opposite to that of the flexible linkages on the other side. Because of this, no net transverse motion is transferred to the sample platform relative to the base. The small transverse motions of the flexible linkages are accommodated by their flexible portions. Accordingly, the sample platform motion is largely decoupled from the horizontal components of motion associated with the arcuate movement of the outer arms of the levers on which the sample platform is supported. The sample platform therefore moves in a direction which is largely parallel to the z-axis. The amount by which the sample platform moves is determined by the amount by which the piezoelectric element expands and the mechanical advantage of the levers. For the example positioner shown in Figures 1 to 5, the effective length of the inner arms of the levers (i.e. the distance between their flexible pivots and the location at which the piezoelectric element acts on them) is one-third of the effective length of the outer arms of the levers (i.e. the distance between their flexible pivots and the flexible linkages). This means that as the piezoelectric element expands by an amount Δz^{pz} , the sample platform is raised by an amount $\Delta z^{sp} = 3\Delta z^{pz}$. Accordingly, the overall range of motion provided by the positioner is three times that of the piezoelectric element itself. Because of the symmetry of the positioner, this amplification is achieved while maintaining a substantially linear motion of the sample platform parallel to the drive axis of the piezoelectric element. It will be appreciated that other amplifications can be achieved by changing the ratio of the effective lengths of the inner and outer arms of the levers. It is even possible to provide a mechanical advantage of less than unity. Although this reduces the overall range of motion for the positioner, it effectively gears-down the expansion or

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contraction of the piezoelectric element. This can help to reduce jitter in the position of the sample platform associated with noise in the drive mechanism. For example, due to electronic noise in the drive signal applied to the piezoelectric element.

5 The sample can be moved further along the z-direction by further expanding the piezoelectric element or the sample can be moved back towards its natural position by contracting the piezoelectric element. It is possible to move the sample downwardly from its natural position by driving the piezoelectric element to contract from its natural configuration. However, a given piezoelectric element will generally allow for a larger range of expansion than it will for contraction. For example, a
10 piezoelectric element might typically be able to contract over a range which is only 10% or so of its expansion range. Accordingly the sample's natural position will typically be selected to correspond to be at or near the lowest position the sample will be required to adopt.

The instantaneous position of the sample platform can be calculated from the
15 positioner's known response to the drive signal applied to the piezoelectric element. Alternatively, it is possible to provide a sensor for making a measurement of the position. This reduces the impact of any long term drifts in the positioner response, and can also be used as a feed-back signal to assist positional stabilisation using a feedback loop.

20 The position measurement may come from the strain gauges 29a, 29b, 29c mounted to the piezoelectric element 8. Outputs from these strain gauges indicate the degree of expansion or contraction of the piezoelectric element 8. From this, the positions of the levers can be determined, and hence the position of the sample platform with respect to the base calculated. In one example, the strain gauges are
25 incorporated into Wheatstone bridge measurement circuitry mounted locally at the positioner. This reduces effects associated with, for example, thermal variations which might otherwise arise between different elements of the Wheatstone bridge.

In other examples, a more direct measure of the position of the sample platform relative to the base can be provided. For example, by having a linear
30 displacement transducer arranged to measure the overlap of neighbouring pairs of the input and output flexible linkages. In other cases, other feedback mechanisms may be

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used, for example externally derived signals which depend on the position of a sample. For example, a reflection or interferometric optical encoder.

It will be appreciated that many other configurations of positioner are possible. For example, a single axis positioner that is not to be incorporated into a multi-axis
5 positioner, could employ rigid linkages in place of the flexible linkages for connecting the main body to the base and sample platform. In such cases, slide bearings or resilient bush mountings could be employed at both the base and sample platform fixings to accommodate any transverse motions associated with the arcuate motion of the lever outer arms.

10 In other examples, the input cross member may be solid such that it does not flex and is instead forms part of, or is rigidly connected to, the base. In such cases the expansion of the piezoelectric element acts wholly on the inner arms of the output levers (there being no input levers). This configuration causes the mounting dowels of the output flexible linkages to have an arcuate, rather than diagonal, motion. The
15 transverse motion component associated with this is again accommodated by the flexibility of the flexible linkages, or by the flexibility of the mountings in cases where rigid linkages are used.

The arrangement of having the input and output flexible linkages doubling-back on one another through the positioner allows relatively long linkages to be used
20 in a small space. This improves the flexibility of the linkages and also provides for a relatively large radius of curvature associated with any transverse motions. This reduces the coupling between the transverse and longitudinal motions of the positioner. However, in some embodiments the flexible linkages may not double back through the positioner, but may instead extend directly away from it. This effectively
25 reverses the direction of motion such that expansion of the piezoelectric element causes the sample platform to move in the opposite direction to that described above.

It will be appreciated that in some examples the output levers, and input levers where present, could be separate elements connected, for example by a leaf spring acting as a flexure hinge, and need not be formed from a single cross member having
30 a cut out to define a flexure hinge. In other examples, the output levers could be separate from one another with no flexure hinge or other direct link between them. In

these cases, load springs of the kind shown in Figures 1 to 4 can be used to replace the functionality of the flexible hinges (i.e. the function of providing load support and a restoring force). A link between the first and second support walls, or other means, could be used to hold the levers correctly in position relative to one another in such cases.

It will also be appreciated that other kinds of flexure pivot might be used as fulcrums for the levers. For example, in an example which does not include a unitary main body, support walls having an knife edges which sit in V-grooves in the levers may be used to provide the flexible pivots.

It will further be appreciated that piezoelectric element may be configured such that the axis of the piezoelectric element itself is not parallel to the drive axis along which it supplies the actuation, or drive, force. For example, the piezoelectric element may be arranged to expand and contract along one direction and a mechanical drive train configured transfer this motion so as to supply an actuation force along a drive axis.

As previously noted, the above has described a positioner for positioning a sample platform relative to a base along a vertical z-axis. It will be understood this particular orientation is arbitrary and the axis of the positioner can be arranged to position the sample platform relative to the base along any desired direction, including "up-side-down" configurations. References made above to upper, lower, upwardly, downwardly, and so forth, relate only to a positioner in the orientation shown in Figures 1 to 4.

Figure 6 schematically shows a perspective view of a positioner 102 according to a second embodiment of the invention. As before, the positioner 102 will be described with reference to a three-dimensional Cartesian co-ordinate system. A legend in the figure indicates the direction of the Cartesian co-ordinates.

The positioner 102 is a three-axis parallel positioner for moving a sample platform (or output stage) 106 relative to a base (or input stage) 104 along the x- y- and z-axes. The outer geometry of the positioner in this example is generally cuboid with a characteristic size of around 55 mm.

Figure 7 schematically shows an exploded perspective view of the sample platform 106 and base 104. The base comprises three faces arranged to form three-faces of a cube. An xy-face 110 lies in an xy-plane, an xz-face 112 lies in an xz-plane and a yz-face 114 lies in a yz-plane. The sample platform similarly comprises three
5 faces arranged to form three-faces of a cube, again having an xy-face 120 lying in an xy-plane, an xz-face 122 lying in an xz-plane and a yz-face 124 lying in a yz-plane. In the assembled positioner 102 shown in Figure 6, the sample platform 106 and base 104 are located near to one another but are not in contact.

As can be seen from Figure 6, the three-axis positioner 102 comprises three
10 one-axis positioners connecting in parallel along three orthogonal axes between the sample platform 106 and the base 104. These three one-axis positioners are an x-axis positioner 2x, a y-axis positioner 2y and a z-axis positioner 2z. Each of these is similar, to and operates in the same way as, the positioner 2 described above and shown in Figures 1 to 5, except that the x-axis and y-axis positioners are differently
15 oriented.

The x-axis positioner 2x is arranged with its drive axis parallel to the x-axis and connects between the yz-face 114 of the base and the yz-face 124 of the sample platform. The mounting dowels for the input flexible linkages of the x-axis positioner 2x fit into holes 76, 78 in the yz-face 114 of the base. These dowels are held in place
20 by respective grub screws 90, 92. The mounting dowels for the output flexible linkages of the x-axis positioner 2x are similarly fixed into holes (not visible) in the yz-face 124 of the sample platform. Accordingly, when the x-axis positioner is driven as described above for the positioner 2 shown in Figures 1 to 5, the sample platform 106 is moved relative to the base 104 along the x-direction.

25 The y-axis positioner 2y is arranged with its drive axis parallel to the y-axis and connects between the xz-face 112 of the base and the xz-face 122 of the sample platform. The mounting dowels for the input flexible linkages of the y-axis positioner 2y fit into holes 72, 74 in the xz-face 112 of the base. These dowels are again held by grub screws. The mounting dowels for the output flexible linkages of the y-axis
30 positioner 2y are similarly fixed into holes 84, 86 in the xz-face 122 of the sample

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platform. Accordingly, when the y-axis positioner is driven, the sample platform 106 is moved relative to the base 104 along the y-direction.

5 The z-axis positioner 2z is arranged with its drive axis parallel to the z-axis and connects between the xy-face 110 of the base and the xy-face 120 of the sample platform. The mounting dowels for the input flexible linkages of the z-axis positioner 2z fit into holes (not visible) in the xy-face 110 of the base. The mounting dowels for the output flexible linkages of the z-axis positioner 2z are fixed into holes 80, 82 in the xy-face 120 of the sample platform. Accordingly, when the z-axis positioner 2z is driven, the sample platform 106 is moved relative to the base 104 along the z-direction.

10 Accordingly, the x-, y- and z-axis positioners may be driven to move and so position the sample platform along all three directions. Because the x-, y- and z-axis positioners each employ flexible linkages for connecting between the base and the sample platform, the positioners associated with each axis are able to accommodate motion along each of the other axes in a manner broadly similar to that described in EP 0 937 961.

Returning to the one axis positioner 2 shown in Figure 2, in some examples the first and second support walls 18, 20 can be made sufficiently thin that they may be flexed outwardly or inwardly. This can be achieved using a suitably mounted actuator. For example a piezoelectric element bonded to an outer face of one of the support walls may be driven to expand so flexing the support wall. One or more strain gauges may also be mounted on the support wall to measure the degree of flexure. Flexing the support wall on one side has the effect of bringing together the opposing pair of input and output levers on that side so as to increase the separation between the base and the sample platform on the same side. Accordingly, flexing the support walls in this way can allow angular positioning of the sample platform shown in Figures 1 to 4 about the y-axis. Employing similar means for flexing the support walls in each of the three positioners shown in Figure 6 provides for a six-axis positioner.

REFERENCES

- [1] US 3 902 084 (Burleigh Instruments Inc.)
- [2] US 3 902 085 (Burleigh Instruments Inc.)
- 5 [3] Dieter Pohl, "Review of Scientific Instruments", vol. 58, p. 54-57 (1986).
- [4] JP 02 119277 (NEC Corp.)
- [5] EP 0 510 698 (NEC Corp.)
- [6] EP 0 937 961 (Melles Griot Ltd.)

CLAIMS

1. A positioner comprising:
a base and a sample platform moveable relative to the base;
5 a drive mechanism arranged to act between the base and the sample platform;
and
a plurality of levers extending away from each other, the levers supporting the
sample platform and being connected to the drive mechanism so that actuation of the
drive mechanism is transmitted under mechanical advantage of the levers to position
10 the sample platform.
2. A positioner according to claim 1, wherein each lever is rotatably mounted on
a fulcrum, thereby subdividing the levers into inner and outer arms with the inner
arms connected to the drive mechanism and the outer arms supporting the sample
15 platform.
3. A positioner according to claim 1 or 2, wherein the drive mechanism is
arranged to act on the levers in the same direction.
- 20 4. A positioner according any of claims 1 to 3, wherein the drive mechanism
comprises a piezoelectric element.
5. A positioner according to any of claims 1 to 4, wherein the plurality of levers
comprises at least one pair of levers that extend in opposite directions to each other.
25
6. A positioner according to any of claims 1 to 5, further comprising a flexible
hinge interconnecting at least some of the levers.
7. A positioner according to claim 6, wherein the levers are formed from a single
30 cross member, the flexible hinge being provided by a thinned section of the cross
member.

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8. A positioner according to any of claims 2 to 7, further comprising support walls that connect to the levers by flexible connections to form the fulcrums.
- 5 9. A positioner according to claim 8, wherein each lever and its support wall are of unitary construction, the flexible connection being provided by a thinned junction section.
- 10 10. A positioner according to any of claims 2 to 9, wherein the fulcrums are moveable relative to one another such that the sample platform may be rotated with respect to the base.
- 15 11. A positioner according to any of claims 1 to 10, wherein the sample platform is mounted on the levers by a pair of output linkages which are stiff in respect of forces applied along their axes of extent.
12. A positioner according to claim 11, wherein the output linkages are deformable in respect of forces applied transverse to their axes of extent.
- 20 13. A positioner according to claim 11 or 12, wherein the output linkages extend away from the levers on the same side as that on which the drive mechanism is located.
- 25 14. A positioner according to any of claims 11 to 13, wherein the output linkages extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.
- 30 15. A positioner according to any of claims 1 to 14, further comprising biasing elements connected to each lever and arranged to resist movement of the levers relative to the base and so provide a restoring force when the levers are moved.

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16. A positioner according to any of claims 1 to 15, further comprising a mechanical stop connected to each lever to limit the amount by which it can move relative to the base.
- 5 17. A positioner according to any of claims 1 to 16, wherein the mechanical advantage of the levers acts to move the sample platform by an amount which is more than the movement of the drive mechanism.
- 10 18. A positioner according to any of claims 1 to 16, wherein the mechanical advantage of the levers acts to move the sample platform by an amount which is less than the movement of the drive mechanism.
- 15 19. A positioner according to any of claims 1 to 18, further comprising one or more strain gauges for measuring the positions of the levers.
20. A positioner according to claim 19, wherein the one or more strain gauges are coupled to respective bridge measuring circuits mounted on the positioner.
- 20 21. A positioner according to any of claims 1 to 20, comprising a further plurality of levers extending away from each other, the further levers being connected to the base and the drive mechanism so that actuation of the drive mechanism is transmitted to the further levers to cause them to move with respect to the base.
- 25 22. A positioner according to claim 21, each further lever being rotatably mounted on a fulcrum, thereby subdividing the further levers into inner and outer arms with the inner arms connected to the drive mechanism and the outer arms connected to the base.
- 30 23. A positioner according to claim 21 or 22, the drive mechanism being arranged to act on each of the further levers in the same direction.

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24. A positioner according to any of claims 21 to 23, the drive mechanism being arranged to act on the further levers in a direction which is different to that in which it acts on the first mentioned levers.
- 5 25. A positioner according to any of claims 21 to 24, each of the further levers being aligned with a corresponding one of the first mentioned levers.
26. A positioner according to any of claims 21 to 25, the further levers being connected together by a flexible hinge.
- 10 27. A positioner according to claim 26, wherein the further levers are formed from a single cross member, the flexible hinge being provided by a thinned section of the cross member.
- 15 28. A positioner according to any of claims 22 to 27 when dependent on claim 8, the support walls also supporting the further levers, the further levers being connected to the support walls by flexible connections for providing the fulcrums.
- 20 29. A positioner according to claim 28, wherein each further lever and its support wall are of unitary construction, the flexible connection being provided by a thinned section at their junction.
30. A positioner according to claim 28 or 29, wherein the first mentioned, levers, the support walls and the further levers are of unitary construction.
- 25 31. A positioner according to any of claims 21 to 30, wherein the further levers are connected to the base by a pair of input linkages which are stiff in respect of forces applied along their axes of extent.
- 30 32. A positioner according to claim 31, wherein the input linkages are deformable in respect of forces applied transverse to their axes of extent.

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33. A positioner according to claim 31 or 32, wherein the input linkages extend away from the input levers on the same side as that on which the drive mechanism is located.

5

34. A positioner according to any of claims 31 to 33, wherein the input linkages extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.

10

35. A positioner according to any of claims 21 to 34, further comprising biasing elements connected to each further lever and arranged to resist movement of the further levers relative to the base and so provide a restoring force when the further levers are moved.

15

36. A positioner according to any of claims 21 to 35, further comprising a mechanical stop connected to each further lever to limit the amount by which it can move relative to the base.

37. A positioner according to any of claims 21 to 36, further comprising one or more strain gauges for measuring the positions of the further levers.

20

38. A positioner according to claim 37, wherein the one or more strain gauges are coupled to respective bridge measuring circuits mounted on the positioner.

25 39. A multi-axis positioner comprising a first positioner according to any of claims 1 to 38 aligned along a first direction and a second positioner according to any of claims 1 to 38 aligned along a second, different, direction, the first and second positioners connecting between a common base and a common sample platform.

30 40. A multi-axis positioner according to claim 39, wherein the first direction and the second direction are orthogonal to one another.

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41. A multi-axis positioner according to claim 39 or 40, further comprising a third
positioner according to any of claims 1 to 38 aligned along a third direction, the third
direction being different to the first and second directions, the third positioner
5 connecting between the common base and the common sample platform.

42. A multi-axis positioner according to claim 41, wherein the third direction is
orthogonally arranged with respect to at least one of the first or second directions.

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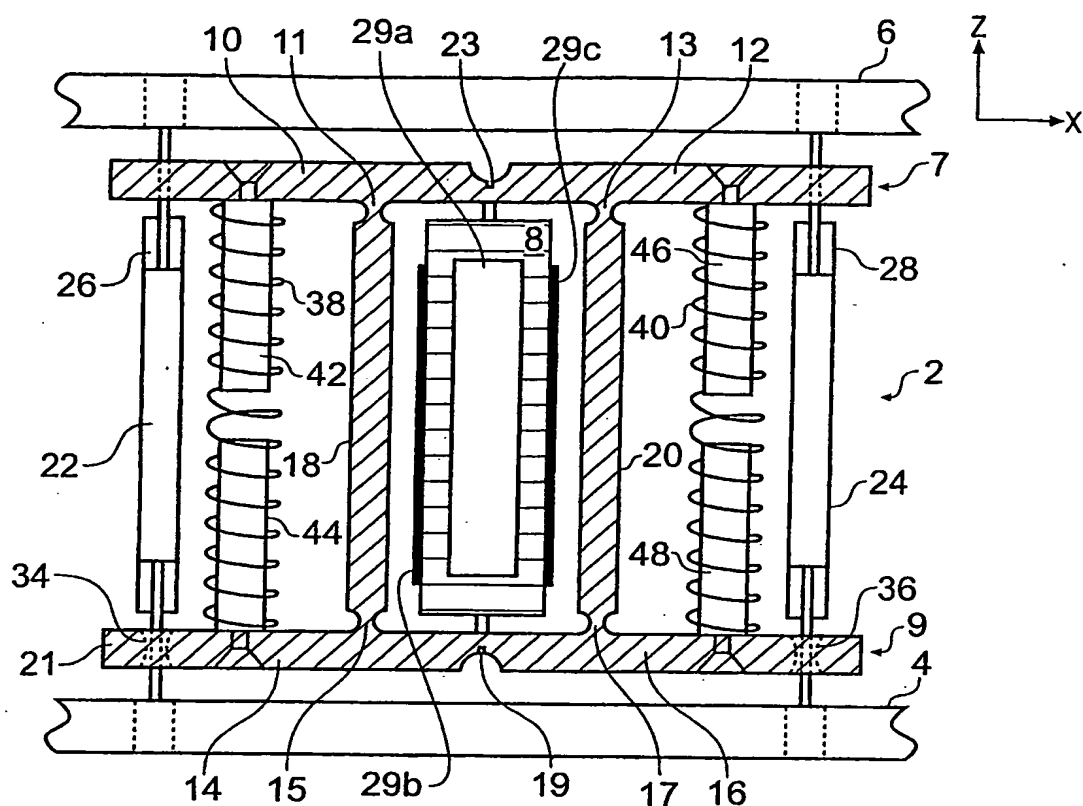
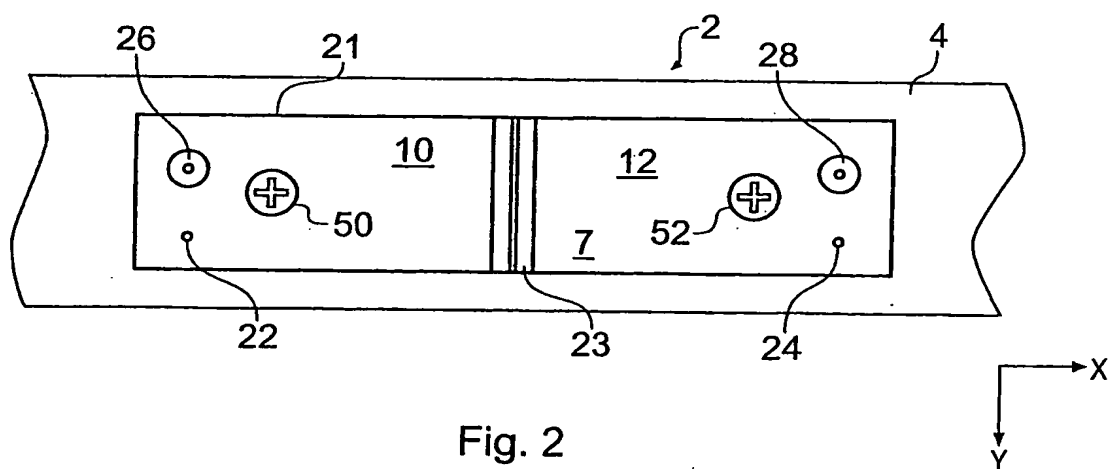


Fig. 1



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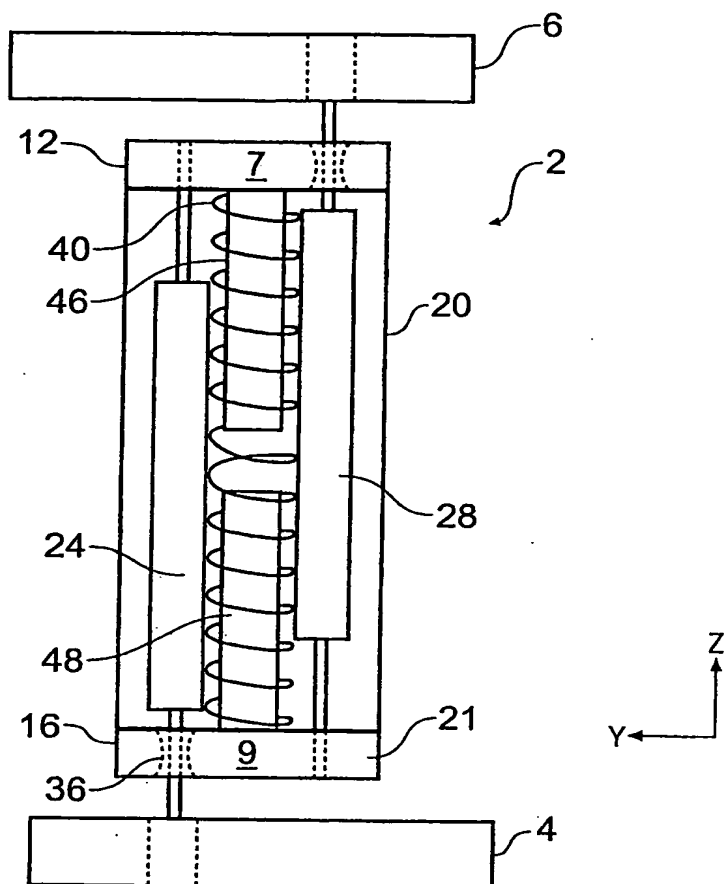


Fig. 3

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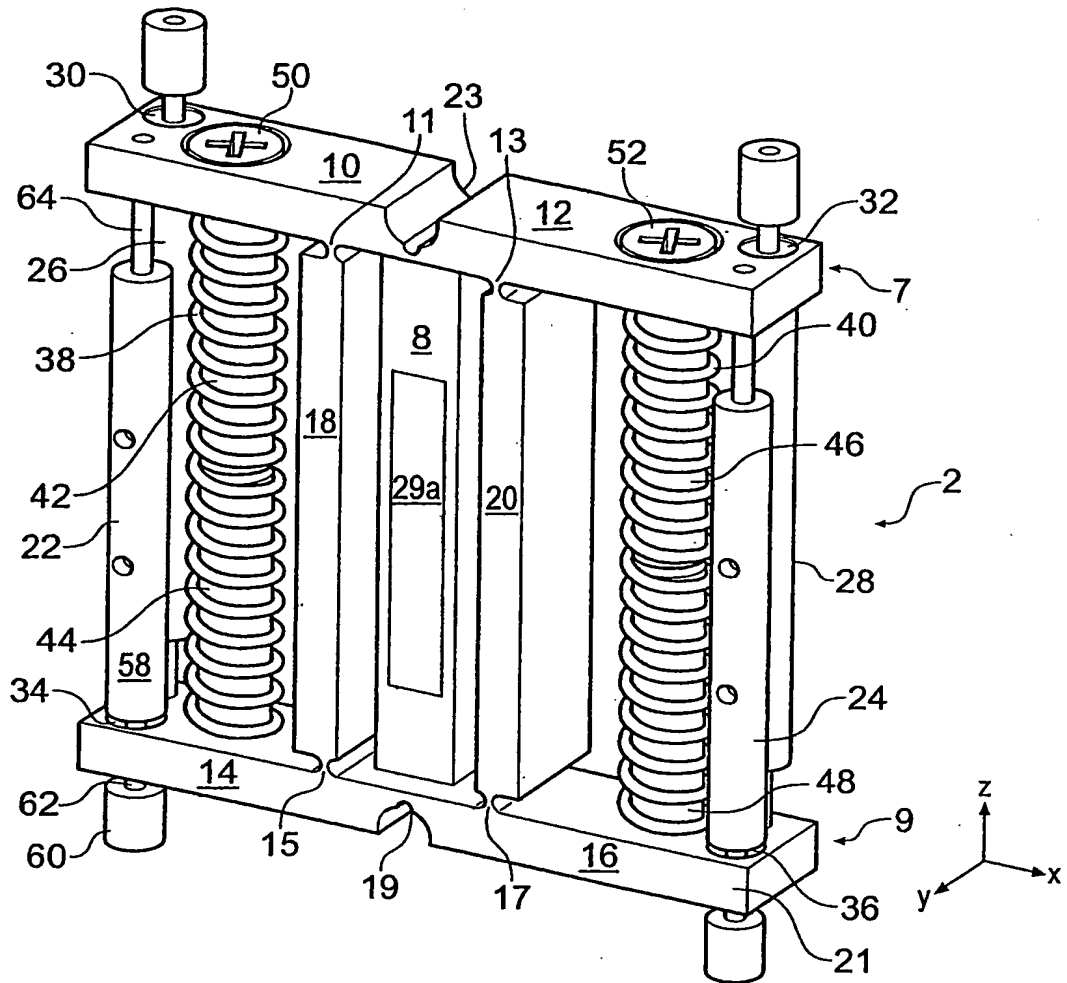


Fig. 4

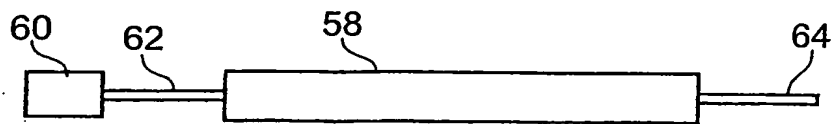


Fig. 5

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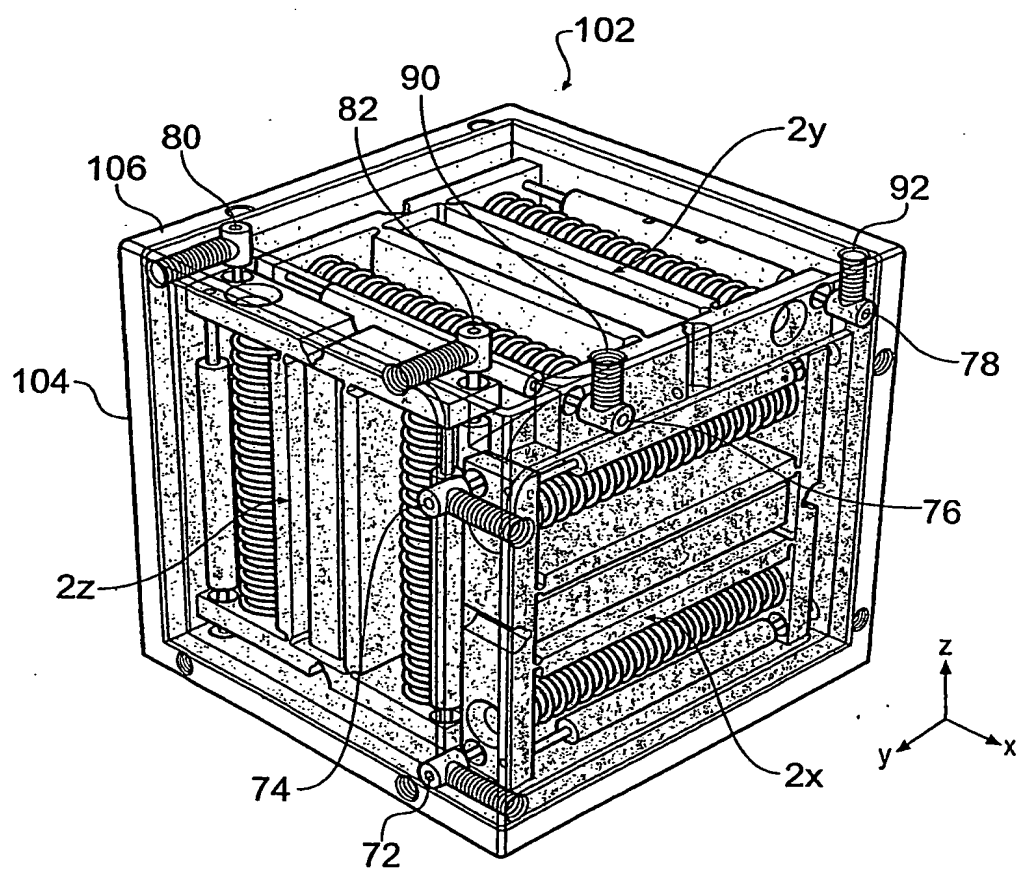


Fig. 6

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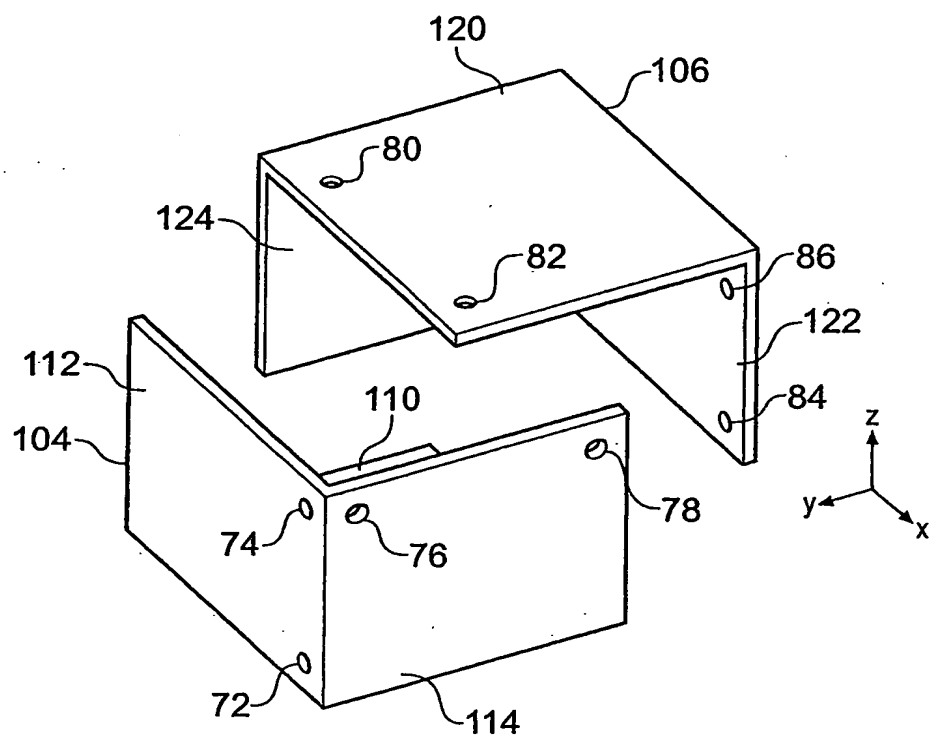


Fig. 7

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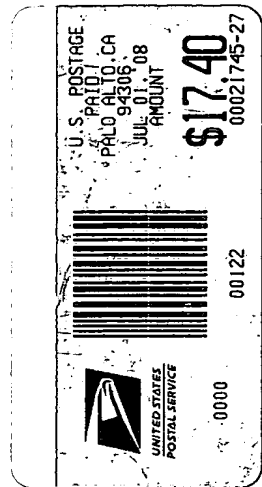
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July 30, 2008

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Via Registered Mail

U.S. Patent Application No.: 10/589,684
Title: Positioner Device
Inventors: Terence J. HERBERT and Michael J. DIXON
Our Reference: 09314.0046

Dear Mr. Herbert:

Enclosed is a Declaration under 37 C.F.R. § 1.131 and an Assignment corresponding to the United States patent application that was filed in the U.S. Patent and Trademark Office on August 16, 2006, for "Positioner Device." A copy of this application is also included for your reference.

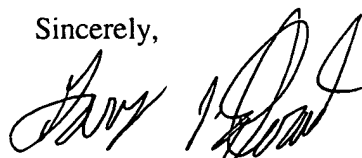
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If you have any questions, please contact me.

Sincerely,



Gary J. Edwards

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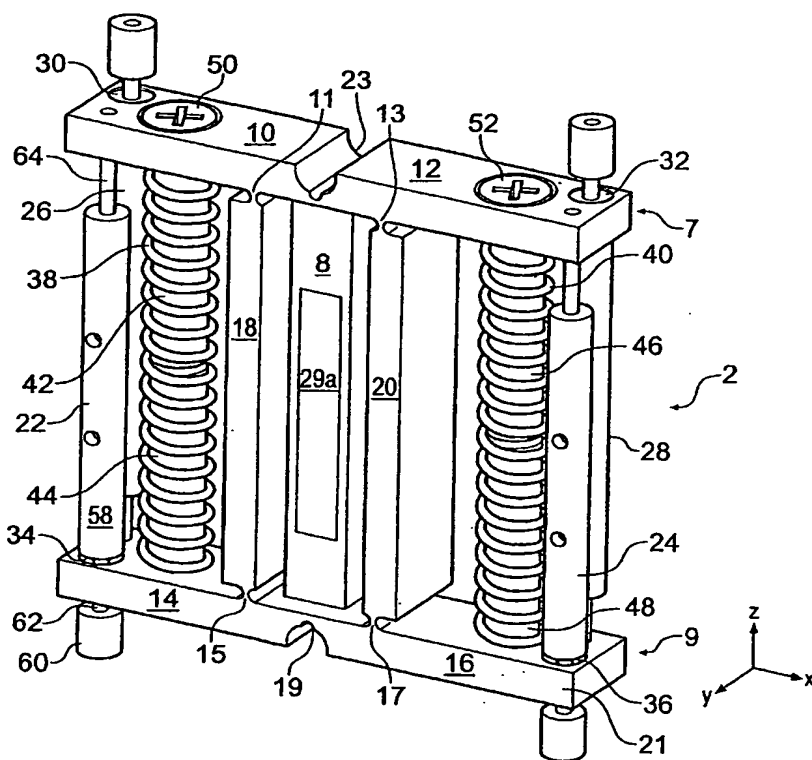
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(54) Title: **POSITIONER DEVICE**



(57) Abstract: A positioner (2) for moving a sample platform (6) relative to a base (4) is described. The positioner is driven by a piezoelectric arranged to expand and contract along a drive axis, the piezoelectric element has an input end coupled to the base and an output end coupled to first (14) and second (16) output levers extending away from the drive axis of the piezoelectric element in opposing directions. The output levers each have an inner arm arranged to be acted on by the piezoelectric element as it expands and an outer arm to which the sample platform is mounted via platform supports (26, 28). The output levers are mounted such that the piezoelectric element acts on the inner arms of the output levers to cause the outer arms to move in a plane containing the drive axis. This motion of the output levers is communicated via the platform supports to the sample platform, so moving it relative to the base along a direction parallel to the drive axis.

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POSITIONER DEVICE

BACKGROUND OF THE INVENTION

5 The invention relates to positioners which are widely used for a variety of applications including the positioning of optical components, both in production lines and in scientific experiments.

One shortcoming of positioners designed to provide a high degree of accuracy in their positioning is that they are often only able operate over a relatively limited range. For example, a number of positioner designs employ piezoelectric drive
10 elements in their drive mechanisms. Piezoelectric drive elements are useful because they are relatively robust and are able to provide repeatable high precision positioning. However, a 38 mm long piezoelectric stack might have a positioning range of only 42 μm . This limited range can mean positioners employing piezoelectric drive elements can be impractical for many applications. Similar problems can arise with other types
15 of high precision drive mechanisms.

US 3 902 084 [1] and US 3 902 085 [2] describe "inchworm positioners" which address this problem. These are one-axis positioners arranged to selectively grip and release opposing ends of a piezoelectric drive element as it is cyclically expanded and contracted. Appropriate control of the piezoelectric drive element and
20 the piezoelectric grips at either end can cause the piezoelectric drive element to inch its way along between the grips during successive expand and contract cycles. Although positioners of this type allow for larger ranges of motion, they are complex designs requiring a number of moving parts which must be separately controlled in a carefully orchestrated manner.

25 Another approach is to use a positioner comprising two elements in frictional engagement with one another which slide relative to one another when the frictional force between them is overcome. Motion is generated by the interplay between inertia of one of the elements and slipping or sticking of the frictional engagement between the elements. Positioners of this kind are referred to as inertial positioners or slip-stick

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positioners and are known for example from an article by Dieter Pohl in the journal "Review of Scientific Instruments" [3]. Inertial slip-stick positioners can be made with relatively few major components. However, known inertial slip-stick positioners have a low load bearing capacity and a high degree of sensitivity to orientation, unlike the above described inchworm positioners.

5 An alternative solution would be to use a lever arrangement to magnify or amplify the motion. JP 02 119277 [4] describes a mechanical amplifier for a piezoelectric drive element, albeit one designed primarily for dot-matrix printer heads. The device of JP 02 119277 employs a pair of hinged levers mounted at opposing
10 ends of a piezoelectric stack such that the lever's outer arms are brought together as their inner arms are pushed apart by the piezoelectric element expanding. A buckle spring connects between the lever's outer arms and buckles outwardly as the lever arms are brought together. The outward motion of the buckle spring provides the useful output of the device. EP 0 510 698 [5] employs principles similar to those of JP
15 02 119277, but has two buckle springs connected in series between the levers. This provides for two simultaneous displacement outputs. Devices of this kind are not generally suitable for the reliable positioning of sample platforms. This is because their sprung nature makes them prone to vibration, and their buckling movement will generally be different for different platform loads. This means samples having
20 different masses will generally be positioned differently for the same expansion of the piezoelectric drive element.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a positioner comprising: a base and a sample platform moveable relative to the base; a drive
5 mechanism arranged to act between the base and the sample platform; and a plurality of levers extending away from each other, the levers supporting the sample platform and being connected to the drive mechanism so that actuation of the drive mechanism is transmitted under mechanical advantage of the levers to position the sample platform.

10 The use of levers allows the motion of the drive mechanism, for example the expansion or contraction of a piezoelectric element, to be amplified before being transmitted to the sample platform. Furthermore, by mounting the sample platform on a plurality of levers extending away from each other, a stable mounting can be achieved which is resistant to torque forces applied by the weight of a sample on the
15 sample platform, for example where the sample is located off-centre. In addition, the use of a plurality of levers allows the arcuate motions associated with each of the individual levers to be combined to provide a linear motion of the sample platform.

Throughout the following, the levers will sometimes be referred to as output levers. This term reflects that they support the sample platform, which may be
20 considered an output stage of the positioner.

Each lever can be rotatably mounted on a fulcrum which subdivides the levers into inner and outer arms with the inner arms being connected to the drive mechanism and the outer arms supporting the sample platform.

This allows for simple lever and drive mechanism configurations. However, it
25 will be appreciated that other configuration are possible. For example, the sample platform and drive mechanism may both be coupled to the output arms, the relative locations of their couplings determining the mechanical advantage.

The drive mechanism may be arranged to act on each of the levers in the same direction such that they move in a similar manner to one another when the drive
30 mechanism is actuated.

The plurality of levers may comprise two levers extending in opposing directions.

The levers may be connected to one another by a flexible hinge. The flexible hinge may be a leaf spring connecting between the levers, for example, or the levers
5 may be formed from a single cross member. The flexible hinge being provided by a thinned section of the cross member.

Connecting the levers in this way provides a restoring force as each of the levers are pivoted about their fulcrums, sometimes referred to as flexible pivots, away from their rest positions. This restoring force provides a support force for the sample
10 platform. By forming the levers from a single cross member, a structurally robust and easy to assemble configuration having a low number of parts can be provided.

Support walls may be used for pivotably supporting the levers at their fulcrums, the levers being connected to the support walls by flexible connections providing the fulcrums which allow them to pivot. Furthermore, each lever and its
15 support wall may be of unitary construction with the flexible connections being provided by thinned sections at the junctions between the levers and support walls.

This kind of flexible pivot provides a further restoring force as each of the levers are pivoted, so increasing the support force for the sample platform. The unitary construction is structurally robust and easy to assemble having a low number of parts.

20 The support walls providing the flexible pivot support may be configured to be independently flexed. For example, a piezoelectric transducer may be bonded to a face of one of support walls which can be driven to expand, so causing the support wall to flex. Flexing one or other (or both) support walls reduces their effective length relative to one another. This can cause relative movement between the fulcrums of the
25 different levers. Because the sample platform is connected to each of the levers, this relative movement between the fulcrums leads to a rotation of the sample platform with respect to the base, so allowing for angular positioning.

The sample platform may be mounted on the levers by a pair of output linkages which are stiff in respect of forces applied parallel to their axes of extent.
30 This allows motion to be reliably transferred from the levers to the sample platform.

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The output linkages may be deformable in respect of forces applied transverse to their axes of extent. This assists the positioner to accommodate the transverse components of the arcuate motion of the levers and so provide the linear motion of the sample platform. In other cases, resilient mountings between the output linkages and the levers and/or the sample platform may be provided to accommodate these transverse motion components.

The flexible output linkages allow the positioner to reliably position the sample platform parallel to the drive axis, even if the sample platform is being moved or is offset relative to the base in a direction which is transverse to the drive axis, the transverse movement being accommodated by flexure of the output linkages. This allows a number of the positioners to be connected in parallel in a multi-axis positioner. For example, two or three orthogonally mounted positioners may be connected between a common base and a common sample platform to provide a two- or three-axis positioner.

The output linkages may extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.

The output linkages may extend away from the levers on the same side as that on which the drive mechanism, or a significant part of it, is located.

This "doubling-back" of the output linkages allows the use of relatively long output linkages in a small space. The use of long output linkages improves their flexibility. In addition, long output linkages provide for a relatively large radius of curvature for the transverse motions associated with either the arcuate motion of the levers, or the transverse motion of the sample platform relative to the base in a multi-axis positioner. Having a large radius of curvature acts to reduce the coupling between the transverse and longitudinal components of the motion of the positioner.

The positioner may further comprise biasing elements, for example springs, e.g. helical springs, connected to each lever and arranged to resist movement of the levers relative to the base. The biasing acts to provide an additional restoring force for the levers as they are moved by the drive mechanism. This further increases the load which the positioner can reliably support and position.

The positioner may further comprise a stop mechanism connected to each lever to limit the amount by which it can move relative to the base. This helps to prevent the positioner from being damaged, for example by being overloaded or over driven by the drive mechanism.

5 In general, the geometry of the levers and the locations at which the sample platform and the drive mechanism are coupled to them, will be such that the sample platform moves by an amount greater than an amount by which the drive mechanism moves. That is to say the mechanical advantage, or mechanical amplification, of the lever's action will be greater than unity. However, in some examples the arrangement
10 will be such the sample platform moves by an amount less than an amount by which the drive mechanism moves. That is to say the mechanical advantage, or mechanical amplification, of the lever's action will be less than unity. This arrangement effectively gears-down the expansion or contraction of the piezoelectric element. This allows a sample to be positioned more accurately than the drive mechanism precision.

15 The positioner may include one or more strain gauges for measuring the position of the levers. There are a number of points at which strain gauges may be mounted. For example, strain gauges may be coupled to the parts drive mechanism. For example, they may be bonded to the side of a piezoelectric element which might form part of the drive mechanism. This allows the movement of the drive mechanism
20 to be measured, from which the positions of the levers can be calculated. From the positions of the levers, the position of the sample platform relative to the base can be determined. Strain gauge output signals can also be used in a feed back control loop to improve the positioning stability, i.e. to provide an encoder device.

 The one or more strain gauges may be coupled to respective bridge measuring
25 circuits. For example, Wheatstone bridge measuring circuits, which are mounted on the positioner itself. This can help to reduce effects arising from temperature differentials between different elements of the bridge circuitry. In some embodiments, a strain gauge may be used in each arm of the bridge circuitry to provide increased sensitivity.

30 The positioner may include a further plurality of levers extending away from each other, the further levers being connected to the base and the drive mechanism so

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that actuation of the drive mechanism is transmitted to the further levers to cause them to move with respect to the base.

Each further lever may be rotatably mounted on a fulcrum, thereby subdividing the further levers into inner and outer arms with the inner arms connected
5 to the drive mechanism and the outer arms connected to the base.

The further levers may be arranged such that the drive mechanism acts on each of the further levers in the same direction. This may be a direction which is different to that in which the drive mechanism acts on the first mentioned, or output, levers.

Throughout the following, the further levers will sometimes be referred to as
10 input levers. This term reflects that they are coupled to the base, which may be considered an input stage of the positioner.

The input levers generally mirror the output levers and so provide a positioner with a high degree of symmetry. It will be understood that the design and construction of the input levers may include a number of features which correspond to those
15 described above for the output levers.

A pair of input linkages may be used for connecting the base to the input levers, the input linkages being stiff in respect of forces applied parallel to their axes of extent but deformable in respect of forces applied transverse thereto. The input linkages may again be doubled-back, i.e. extending away from the input levers on the
20 same side as that on which the drive mechanism is located, to allow for long linkages in a small space.

By providing a highly symmetric design such as this, movement of the drive mechanism can be transferred to the sample platform via a combined motion of the output and input levers. This means the output levers only need pivot by
25 approximately half the amount they would otherwise do if there were no input levers to accommodate part of the motion of the drive mechanism. This reduces residual effects associated with the arcuate motion of the levers.

The highly symmetric design additionally reduces the number of different component parts of the positioner, so providing for more simple manufacture.

30 According to a second aspect of the invention there is provided a multi-axis positioner comprising a first positioner according to the first aspect of the invention

aligned along a first direction and a second positioner according to the first aspect of the invention aligned along a second, different, direction, the first and second positioners connecting between a common base and a common sample platform.

5 The multi axis-positioner may further comprise a third positioner according to the first aspect of the invention aligned along a third direction, the third direction being different to the first and second directions, the third positioner connecting between the common base and the common sample platform.

10 In this way, a multi-axis positioner having a parallel mechanism may be provided having up to six degrees of freedom. Where six degrees of freedom are not required, fewer may be provided. For example, the third positioner might not provide for rotation of the sample platform, such that a five-axis positioner is provided.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention and to show how the same may be carried into effect reference is now made by way of example to the accompanying
5 drawings in which:

Figure 1 schematically shows a front view of a one-axis positioner according to a first embodiment of the invention;

Figure 2 schematically shows an end view of the positioner shown in Figure 1;

Figure 3 schematically shows a side view of the positioner shown in Figure 1;

10 Figure 4 schematically shows a perspective view of the positioner shown in Figure 1;

Figure 5 schematically shows a flexible linkage of the positioner shown in Figure 1;

15 Figure 6 schematically shows a perspective view of a three-axis positioner according to a second embodiment of the invention; and

Figure 7 schematically shows an exploded perspective view of a base and a sample platform for the positioner shown in Figure 6.

DETAILED DESCRIPTION

Figures 1, 2, 3 and 4 schematically show respective front, end, side and perspective views of a positioner 2 according to a first embodiment of the invention.

- 5 The positioner 2 is described with reference to a three-dimensional Cartesian coordinate system and terms such as upper and lower refer to the orientation shown in Figure 1. It will be appreciated, however, that the positioner can be equally be used in other orientations. The front view of Figure 1 is taken along a y-axis, the end view of Figure 2 is taken along a z-axis and the side view of Figure 3 is taken along an x-axis.
- 10 A legend in each figure indicates the Cartesian plane of the figure.

The positioner 2 is a one-axis positioner for moving a sample platform (or output stage) 6 relative to a base (or input stage) 4 along the z-axis. (The sample platform 6 is not shown in Figures 2 or 4 and the base 4 is also not shown in Figure 4). The positioner in this example has a characteristic size of around 55 mm in the x- and z-directions and about 15 mm in the y-direction. However, it is noted the design is inherently scalable so these dimensions could be much smaller or larger if desired. In fact, the design could be useful for a micro-electromechanical system (MEMS) or nano-technology environment implemented in semiconductor materials using etch technology. The positioner comprises a main body member 21 made of stainless steel,

15 a piezoelectric element 8, a pair of input flexible linkages 22, 24 connecting the main body 21 to the base 4, a pair of output flexible linkages 26, 28 connecting the main body 21 to the sample platform 4, load springs 38, 40 and mounting spigots 42, 44, 46, 48 for the load springs. The piezoelectric element 8 is schematically illustrated as a stack, but it will be understood that a tube or other form of piezoelectric element

20 could be used. Other kinds of actuator, such as a driven screw, may also be used.

In this example, the main body 21 is of unitary construction and comprises an input cross member 7 to which the input flexible linkages 22, 24 are attached and an output cross member 9 to which the output flexible linkages 26, 28 are attached. The input and output cross members 7, 9 are separated from one another by first and second support walls 18, 20. The input cross member 7 has a cut-out in its upper face running parallel to the y-axis. This provides for an input flexure hinge 23 which

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allows the input cross member to flex at its centre. The output cross member 9 has a similar cut-out in its lower face. This provides for an output flexure hinge 19 which allows the output cross member to flex at its centre. The connections between the respective ends of the first and second support walls 18, 20 and the input and output cross members 7, 9 comprise thinned sections of the main body 21 extend along the y-direction so as to provide respective flexure pivots 11, 13, 15, 17 which act as fulcrums.

The combination of flexure hinges 23, 19 in the cross members 7, 9 and the flexure pivots 11, 13, 15, 17 provide for four levers 10, 12, 14, 16. The input cross member 7 is divided by its flexure hinge 23 into a first input lever 10 and a second input lever 12 with respective ones of the flexible pivots 11, 13 providing fulcrums for each of the input levers. The output cross member 9 is divided by its flexure hinge 19 into a first output lever 14 and a second output lever 16 with respective ones of the flexible pivots 15, 17 providing fulcrums for each of the output levers. Accordingly, the input and output levers to one side of the piezoelectric element 8 form a first opposing pair of input and output levers 10, 14 while the input and output levers to the other side of the piezoelectric element 8 form a second opposing pair of input and output levers 12, 16. Each lever 10, 12, 14, 16 is subdivided by its respective flexible pivot 11, 13, 15, 17 into an inner arm and an outer arm. The inner arms of the levers are those parts extending inwardly from the flexible pivots towards the flexure hinges. The outer arms are those parts of the levers extending outwardly away from the flexure hinges.

The piezoelectric element 8 extends between the input and output cross members 7, 9 and is positioned between the support walls 18, 20. The piezoelectric element is arranged so as to expand and contract along the z-axis when driven by an appropriate drive signal. The piezoelectric element has an input end adjacent the input cross member 7 and an output end adjacent the output cross member 8. The interfaces between the ends of the piezoelectric element 8 and the cross members 7, 9 are arranged such that the cross members may flex at their flexure hinges without damaging the piezoelectric element. This can be achieved, for example, by employing a bearing pad having a limited contact area aligned with the flexure hinges of the cross

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members. The piezoelectric element 8 is dimensioned slightly longer than the gap into which it is to be placed. The piezoelectric element is inserted into this undersized gap by first forcing the outer arms of opposing pairs of the input and output levers together. This causes the levers 10, 12, 14, 16 to pivot about their respective flexure pivots 11, 13, 15, 17 such that the gap into which the piezoelectric element is fitted is increased, and the piezoelectric element can be inserted. Once the piezoelectric element is in place, the force applied to the outer arms of the levers is removed so that the main body attempts to re-adopt its unstressed configuration. However, it is prevented from doing so fully by the additional length of the piezoelectric element. This ensures the piezoelectric element is kept under compression. This pre-stressing of the piezoelectric element improves its operating characteristics, as is well known.

A strain gauge is bonded to each side of the piezoelectric element. Three of the strain gauges 29a, 29b, 29c can be seen in Figure 1. Each strain gauge is configured to measure the degree of expansion or contraction of the piezoelectric element 8. It will be appreciated that the expansion or contraction of the piezoelectric element 8 could be measured using other strain gauge configurations. For example, only one strain gauge might be used. However, multiple strain gauges can provide improved sensitivity.

Figure 5 is a schematic cross-section view of one of the input flexible linkages 22 used to connect the input cross member 7 to the base 4. The other flexure linkages 24, 26, 28 are identical in structure to the flexure linkage 22 shown in Figure 5, although are differently installed in the positioner 2. The linkage is rigid in respect of forces applied along its axis of extent, but flexible in respect of transversely applied forces. It will be appreciated that in some single axis embodiments of the invention, the flexible linkages 22, 24, 26, 28 could be replaced with rigid linkages which are not deformable in respect of transversely applied forces. However, as will be seen further below, flexible linkages of the kind shown in Figure 5 allow for a positioner which can be easily integrated into a multi-axis positioner. The flexure linkage 22 contains a rigid central body 58 with a mounting dowel 60 attached to one end by a flexible portion 62. A similar flexible portion 64 extends from the other end of the central body but terminates freely. The central body and mounting dowel are made of 3 mm

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diameter stainless steel rod. The flexible portions are made of 1 mm diameter music wire. The mounting dowel is around 5 mm long and the central body is around 25 mm long. The music wire is received into bores in the central body and the mounting dowel such that approximately 10 mm is left exposed between the central body and the mounting dowel and around 15 mm is left exposed on the other side. The flexible linkage 22 has an overall length of around 55 mm. Because the sections of music wire are relatively short, the flexible linkage has a relatively high longitudinal stiffness but is free to flex in the transverse direction. Linkages of this kind are further described in EP 0 937 961 [6].

As can be seen from Figure 4, input flexible linkage 22 is installed in the positioner 2 such that the free-end flexible portion 64 is fixedly connected near the edge of the outer arm of input lever 10. The linkage then extends substantially parallel to the z-axis towards output lever 14, the central body 58 being disposed between the opposing lever arms 10, 14. The flexible portion 62 to which the mounting dowel is attached passes through a rubber bushing 34 in the output lever 14. The rubber bushing 34 allows the input flexible linkage 22 to slide freely in a direction parallel to its axis of extent, but not transversely to this axis. A degree of damping is provided by the rubber bushing and this helps to reduce vibrational noise in the positioner. With the positioner 2 in the orientation shown in Figure 4, the mounting dowel 60 is located beneath the output lever 14. As mentioned above, the base 4 is not shown in Figure 4. However, as can be seen from Figure 1, the mounting dowel 60 is received into an opening in the base where it is held in place, for example by gluing or using grub screws.

The other flexible input linkage 24 is installed in a similar fashion, connecting between the input lever 12 and output lever 14, and passing through rubber bushing 36. The mounting dowel of flexible linkage 24 is similarly attached to the base 4. Accordingly, the positioner 2 is supported with respect to the base 4 by the two input flexible linkages. Because the input flexible linkages are longitudinally rigid, the parts of the outer arms of the input levers to which the input flexible linkages attach are fixed relative to the base along the z-direction. However, because of their flexibility to transverse forces, the parts of the outer arms of the input levers to which the input

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flexible linkages attach may be moved in the x- and y-directions. It will be appreciated that this motion will be arcuate in the xz- and yz-planes respectively, but for ease of explanation, they are described by the direction of their largest component.

5 The output flexible linkages 26, 28 are installed in an overall similar fashion to the input flexible linkages 22, 24, but, rather than connecting the base to the input levers, they connect the output levers to the sample platform. That is to say, the free end flexible portions of the output flexible linkages are fixedly connected near the edge of the outer arms of respective ones of the output levers 14, 16. The linkages then extend substantially parallel to the z-axis towards input levers 10, 12. For the
10 orientation shown in Figure 4, the mounting dowels of the output flexible linkages are located above the input levers 10, 12. The sample platform 6 is not shown in Figure 4. However, as can be seen from Figure 1, the mounting dowels of the output flexible linkages are received into openings in the sample platform where they are held in place.

15 Accordingly, the sample platform 6 is supported relative to the base along the z-axis via the output flexible linkages which connect it to the main body 21 which in turn is supported by the input flexible linkages which connect it to the base. The Sample platform is free to move in the x- and y-directions. If this is not desired, support rails or other bracing could be used.

20 For a positioner in the orientation shown in Figures 1 to 4, the weight of a sample on the sample platform applies a load force which is transmitted from the sample platform 6 along the output flexure linkages 26, 28 so as to act downwardly on the outer arms of the output levers 14, 16. The reaction force supporting the weight of the sample is transmitted from the base 4 along the input flexure linkages 22, 24 so as
25 to act upwardly on the outer arms of the input levers 10, 12. The net effect of this is that opposing pairs of input and output levers are urged apart. This motion is resisted by the resilience of the flexure hinges 17 and 19, the resilience of the flexure pivots 11, 13, 15, 17 and the resistance to compression of the piezoelectric element 8. To increase the useful load that the positioner can support without damaging the flexure
30 hinges, flexure pivot or the piezoelectric element 8 and to provide a positive force against displacements, load springs 38, 40 are used. These connect between the outer

arms of each opposing pair of input and output levers to provide additional support for the sample platform by effectively increasing the rigidity main body 21. One of the load springs 38 is mounted on a pair of spigots 42, 44 respectively connected to one opposing pair of input and output levers 10, 14. The other load spring 40 is mounted
5 on a similar pair of spigots 46, 48 connected to the other opposing pair of input and output levers 12, 16. The spigots are held in place by screw fixings, two of which 50, 52 can be seen in Figures 2 and 4.

The individual pairs of spigots connected to opposing pairs of lever arms are sized such that between them they extend across much of the gap between the input
10 and output lever arms. However, the pairs of spigots do not meet. In the positioner's natural, or rest, configuration (i.e. with no drive signal applied to the piezoelectric element), the spigots are separated by a distance that is approximately one-and-a-half times their expected range of travel during normal use of the positioner 2. This allows the positioner to cover its range of travel freely, but provides protection against
15 attempts to significantly exceed this range as this would cause the spigots to meet. Accordingly, the spigots act as mechanical stops or abutments. Other stop configurations are possible, though it is convenient to combine the stops with the spigot. Safety margins other than 50% are of course possible.

A sample mounted on the sample platform 6 may be moved to a desired
20 position along the z-direction by driving the piezoelectric element 8 to expand or contract. In its natural configuration (i.e. no drive signal applied) the positioner supports the sample at a position z_0 along the z-direction, this is referred to as its natural position or rest position. The z co-ordinate is taken to increase upwardly as indicated by the legend in Figure 1. To move the sample upwardly (i.e. increasing z)
25 from its natural position, a drive signal from a controller (not shown) is applied to the piezoelectric element such that it is driven to expand by an amount Δz^{pz} . The expansion of the piezoelectric element acts on the inner arms of the input and output levers such that the outer arms of opposing pairs of the input and output levers are brought together as the levers pivot about their respective flexible pivots. Because of
30 the arrangement of input and output flexible linkages, this causes the sample platform 6, and hence the sample supported on it, to move upwardly away from the base 4.

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Although the motion of the individual lever arms is arcuate in the plane containing the z-axis of the piezoelectric element, the symmetric motion of the input and output lever arms causes the flexible linkage to move slightly diagonally. Accordingly, as the sample platform raises, in addition to moving relative to each other along the z-direction, the input and output flexible linkages also move inwardly towards the piezoelectric element by a small amount. Because of the symmetry of the positioner about a yz-plane running through the centre of the piezoelectric element, the flexible linkages on one side of the piezoelectric element move inwardly by an amount which is equal and opposite to that of the flexible linkages on the other side. Because of this, no net transverse motion is transferred to the sample platform relative to the base. The small transverse motions of the flexible linkages are accommodated by their flexible portions. Accordingly, the sample platform motion is largely decoupled from the horizontal components of motion associated with the arcuate movement of the outer arms of the levers on which the sample platform is supported. The sample platform therefore moves in a direction which is largely parallel to the z-axis. The amount by which the sample platform moves is determined by the amount by which the piezoelectric element expands and the mechanical advantage of the levers. For the example positioner shown in Figures 1 to 5, the effective length of the inner arms of the levers (i.e. the distance between their flexible pivots and the location at which the piezoelectric element acts on them) is one-third of the effective length of the outer arms of the levers (i.e. the distance between their flexible pivots and the flexible linkages). This means that as the piezoelectric element expands by an amount Δz^{pz} , the sample platform is raised by an amount $\Delta z^{sp} = 3\Delta z^{pz}$. Accordingly, the overall range of motion provided by the positioner is three times that of the piezoelectric element itself. Because of the symmetry of the positioner, this amplification is achieved while maintaining a substantially linear motion of the sample platform parallel to the drive axis of the piezoelectric element. It will be appreciated that other amplifications can be achieved by changing the ratio of the effective lengths of the inner and outer arms of the levers. It is even possible to provide a mechanical advantage of less than unity. Although this reduces the overall range of motion for the positioner, it effectively gears-down the expansion or

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contraction of the piezoelectric element. This can help to reduce jitter in the position of the sample platform associated with noise in the drive mechanism. For example, due to electronic noise in the drive signal applied to the piezoelectric element.

5 The sample can be moved further along the z-direction by further expanding the piezoelectric element or the sample can be moved back towards its natural position by contracting the piezoelectric element. It is possible to move the sample downwardly from its natural position by driving the piezoelectric element to contract from its natural configuration. However, a given piezoelectric element will generally allow for a larger range of expansion than it will for contraction. For example, a
10 piezoelectric element might typically be able to contract over a range which is only 10% or so of its expansion range. Accordingly the sample's natural position will typically be selected to correspond to be at or near the lowest position the sample will be required to adopt.

The instantaneous position of the sample platform can be calculated from the
15 positioner's known response to the drive signal applied to the piezoelectric element. Alternatively, it is possible to provide a sensor for making a measurement of the position. This reduces the impact of any long term drifts in the positioner response, and can also be used as a feed-back signal to assist positional stabilisation using a feedback loop.

20 The position measurement may come from the strain gauges 29a, 29b, 29c mounted to the piezoelectric element 8. Outputs from these strain gauges indicate the degree of expansion or contraction of the piezoelectric element 8. From this, the positions of the levers can be determined, and hence the position of the sample platform with respect to the base calculated. In one example, the strain gauges are
25 incorporated into Wheatstone bridge measurement circuitry mounted locally at the positioner. This reduces effects associated with, for example, thermal variations which might otherwise arise between different elements of the Wheatstone bridge.

In other examples, a more direct measure of the position of the sample platform relative to the base can be provided. For example, by having a linear
30 displacement transducer arranged to measure the overlap of neighbouring pairs of the input and output flexible linkages. In other cases, other feedback mechanisms may be

used, for example externally derived signals which depend on the position of a sample. For example, a reflection or interferometric optical encoder.

It will be appreciated that many other configurations of positioner are possible. For example, a single axis positioner that is not to be incorporated into a multi-axis
5 positioner, could employ rigid linkages in place of the flexible linkages for connecting the main body to the base and sample platform. In such cases, slide bearings or resilient bush mountings could be employed at both the base and sample platform fixings to accommodate any transverse motions associated with the arcuate motion of the lever outer arms.

10 In other examples, the input cross member may be solid such that it does not flex and is instead forms part of, or is rigidly connected to, the base. In such cases the expansion of the piezoelectric element acts wholly on the inner arms of the output levers (there being no input levers). This configuration causes the mounting dowels of the output flexible linkages to have an arcuate, rather than diagonal, motion. The
15 transverse motion component associated with this is again accommodated by the flexibility of the flexible linkages, or by the flexibility of the mountings in cases where rigid linkages are used.

The arrangement of having the input and output flexible linkages doubling-back on one another through the positioner allows relatively long linkages to be used
20 in a small space. This improves the flexibility of the linkages and also provides for a relatively large radius of curvature associated with any transverse motions. This reduces the coupling between the transverse and longitudinal motions of the positioner. However, in some embodiments the flexible linkages may not double back through the positioner, but may instead extend directly away from it. This effectively
25 reverses the direction of motion such that expansion of the piezoelectric element causes the sample platform to move in the opposite direction to that described above.

It will be appreciated that in some examples the output levers, and input levers where present, could be separate elements connected, for example by a leaf spring acting as a flexure hinge, and need not be formed from a single cross member having
30 a cut out to define a flexure hinge. In other examples, the output levers could be separate from one another with no flexure hinge or other direct link between them. In

these cases, load springs of the kind shown in Figures 1 to 4 can be used to replace the functionality of the flexible hinges (i.e. the function of providing load support and a restoring force). A link between the first and second support walls, or other means, could be used to hold the levers correctly in position relative to one another in such cases.

It will also be appreciated that other kinds of flexure pivot might be used as fulcrums for the levers. For example, in an example which does not include a unitary main body, support walls having an knife edges which sit in V-grooves in the levers may be used to provide the flexible pivots.

It will further be appreciated that piezoelectric element may be configured such that the axis of the piezoelectric element itself is not parallel to the drive axis along which it supplies the actuation, or drive, force. For example, the piezoelectric element may be arranged to expand and contract along one direction and a mechanical drive train configured transfer this motion so as to supply an actuation force along a drive axis.

As previously noted, the above has described a positioner for positioning a sample platform relative to a base along a vertical z-axis. It will be understood this particular orientation is arbitrary and the axis of the positioner can be arranged to position the sample platform relative to the base along any desired direction, including "up-side-down" configurations. References made above to upper, lower, upwardly, downwardly, and so forth, relate only to a positioner in the orientation shown in Figures 1 to 4.

Figure 6 schematically shows a perspective view of a positioner 102 according to a second embodiment of the invention. As before, the positioner 102 will be described with reference to a three-dimensional Cartesian co-ordinate system. A legend in the figure indicates the direction of the Cartesian co-ordinates.

The positioner 102 is a three-axis parallel positioner for moving a sample platform (or output stage) 106 relative to a base (or input stage) 104 along the x- y- and z-axes. The outer geometry of the positioner in this example is generally cuboid with a characteristic size of around 55 mm.

Figure 7 schematically shows an exploded perspective view of the sample platform 106 and base 104. The base comprises three faces arranged to form three-faces of a cube. An xy-face 110 lies in an xy-plane, an xz-face 112 lies in an xz-plane and a yz-face 114 lies in a yz-plane. The sample platform similarly comprises three
5 faces arranged to form three-faces of a cube, again having an xy-face 120 lying in an xy-plane, an xz-face 122 lying in an xz-plane and a yz-face 124 lying in a yz-plane. In the assembled positioner 102 shown in Figure 6, the sample platform 106 and base 104 are located near to one another but are not in contact.

As can be seen from Figure 6, the three-axis positioner 102 comprises three
10 one-axis positioners connecting in parallel along three orthogonal axes between the sample platform 106 and the base 104. These three one-axis positioners are an x-axis positioner 2x, a y-axis positioner 2y and a z-axis positioner 2z. Each of these is similar, to and operates in the same way as, the positioner 2 described above and shown in Figures 1 to 5, except that the x-axis and y-axis positioners are differently
15 oriented.

The x-axis positioner 2x is arranged with its drive axis parallel to the x-axis and connects between the yz-face 114 of the base and the yz-face 124 of the sample platform. The mounting dowels for the input flexible linkages of the x-axis positioner 2x fit into holes 76, 78 in the yz-face 114 of the base. These dowels are held in place
20 by respective grub screws 90, 92. The mounting dowels for the output flexible linkages of the x-axis positioner 2x are similarly fixed into holes (not visible) in the yz-face 124 of the sample platform. Accordingly, when the x-axis positioner is driven as described above for the positioner 2 shown in Figures 1 to 5, the sample platform 106 is moved relative to the base 104 along the x-direction.

25 The y-axis positioner 2y is arranged with its drive axis parallel to the y-axis and connects between the xz-face 112 of the base and the xz-face 122 of the sample platform. The mounting dowels for the input flexible linkages of the y-axis positioner 2y fit into holes 72, 74 in the xz-face 112 of the base. These dowels are again held by grub screws. The mounting dowels for the output flexible linkages of the y-axis
30 positioner 2y are similarly fixed into holes 84, 86 in the xz-face 122 of the sample

platform. Accordingly, when the y-axis positioner is driven, the sample platform 106 is moved relative to the base 104 along the y-direction.

The z-axis positioner 2z is arranged with its drive axis parallel to the z-axis and connects between the xy-face 110 of the base and the xy-face 120 of the sample platform. The mounting dowels for the input flexible linkages of the z-axis positioner 2z fit into holes (not visible) in the xy-face 110 of the base. The mounting dowels for the output flexible linkages of the z-axis positioner 2z are fixed into holes 80, 82 in the xy-face 120 of the sample platform. Accordingly, when the z-axis positioner 2z is driven, the sample platform 106 is moved relative to the base 104 along the z-direction.

Accordingly, the x-, y- and z-axis positioners may be driven to move and so position the sample platform along all three directions. Because the x-, y- and z-axis positioners each employ flexible linkages for connecting between the base and the sample platform, the positioners associated with each axis are able to accommodate motion along each of the other axes in a manner broadly similar to that described in EP 0 937 961.

Returning to the one axis positioner 2 shown in Figure 2, in some examples the first and second support walls 18, 20 can be made sufficiently thin that they may be flexed outwardly or inwardly. This can be achieved using a suitably mounted actuator. For example a piezoelectric element bonded to an outer face of one of the support walls may be driven to expand so flexing the support wall. One or more strain gauges may also be mounted on the support wall to measure the degree of flexure. Flexing the support wall on one side has the effect of bringing together the opposing pair of input and output levers on that side so as to increase the separation between the base and the sample platform on the same side. Accordingly, flexing the support walls in this way can allow angular positioning of the sample platform shown in Figures 1 to 4 about the y-axis. Employing similar means for flexing the support walls in each of the three positioners shown in Figure 6 provides for a six-axis positioner.

REFERENCES

- [1] US 3 902 084 (Burleigh Instruments Inc.)
- [2] US 3 902 085 (Burleigh Instruments Inc.)
- 5 [3] Dieter Pohl, "Review of Scientific Instruments", vol. 58, p. 54-57 (1986).
- [4] JP 02 119277 (NEC Corp.)
- [5] EP 0 510 698 (NEC Corp.)
- [6] EP 0 937 961 (Melles Griot Ltd.)

CLAIMS

1. A positioner comprising:
a base and a sample platform moveable relative to the base;
5 a drive mechanism arranged to act between the base and the sample platform;
and
a plurality of levers extending away from each other, the levers supporting the
sample platform and being connected to the drive mechanism so that actuation of the
drive mechanism is transmitted under mechanical advantage of the levers to position
10 the sample platform.
2. A positioner according to claim 1, wherein each lever is rotatably mounted on
a fulcrum, thereby subdividing the levers into inner and outer arms with the inner
arms connected to the drive mechanism and the outer arms supporting the sample
15 platform.
3. A positioner according to claim 1 or 2, wherein the drive mechanism is
arranged to act on the levers in the same direction.
- 20 4. A positioner according any of claims 1 to 3, wherein the drive mechanism
comprises a piezoelectric element.
5. A positioner according to any of claims 1 to 4, wherein the plurality of levers
comprises at least one pair of levers that extend in opposite directions to each other.
25
6. A positioner according to any of claims 1 to 5, further comprising a flexible
hinge interconnecting at least some of the levers.
7. A positioner according to claim 6, wherein the levers are formed from a single
30 cross member, the flexible hinge being provided by a thinned section of the cross
member.

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8. A positioner according to any of claims 2 to 7, further comprising support walls that connect to the levers by flexible connections to form the fulcrums.
- 5 9. A positioner according to claim 8, wherein each lever and its support wall are of unitary construction, the flexible connection being provided by a thinned junction section.
- 10 10. A positioner according to any of claims 2 to 9, wherein the fulcrums are moveable relative to one another such that the sample platform may be rotated with respect to the base.
- 15 11. A positioner according to any of claims 1 to 10, wherein the sample platform is mounted on the levers by a pair of output linkages which are stiff in respect of forces applied along their axes of extent.
12. A positioner according to claim 11, wherein the output linkages are deformable in respect of forces applied transverse to their axes of extent.
- 20 13. A positioner according to claim 11 or 12, wherein the output linkages extend away from the levers on the same side as that on which the drive mechanism is located.
- 25 14. A positioner according to any of claims 11 to 13, wherein the output linkages extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.
- 30 15. A positioner according to any of claims 1 to 14, further comprising biasing elements connected to each lever and arranged to resist movement of the levers relative to the base and so provide a restoring force when the levers are moved.

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16. A positioner according to any of claims 1 to 15, further comprising a mechanical stop connected to each lever to limit the amount by which it can move relative to the base.
- 5 17. A positioner according to any of claims 1 to 16, wherein the mechanical advantage of the levers acts to move the sample platform by an amount which is more than the movement of the drive mechanism.
- 10 18. A positioner according to any of claims 1 to 16, wherein the mechanical advantage of the levers acts to move the sample platform by an amount which is less than the movement of the drive mechanism.
- 15 19. A positioner according to any of claims 1 to 18, further comprising one or more strain gauges for measuring the positions of the levers.
- 20 20. A positioner according to claim 19, wherein the one or more strain gauges are coupled to respective bridge measuring circuits mounted on the positioner.
21. A positioner according to any of claims 1 to 20, comprising a further plurality of levers extending away from each other, the further levers being connected to the base and the drive mechanism so that actuation of the drive mechanism is transmitted to the further levers to cause them to move with respect to the base.
- 25 22. A positioner according to claim 21, each further lever being rotatably mounted on a fulcrum, thereby subdividing the further levers into inner and outer arms with the inner arms connected to the drive mechanism and the outer arms connected to the base.
- 30 23. A positioner according to claim 21 or 22, the drive mechanism being arranged to act on each of the further levers in the same direction.

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24. A positioner according to any of claims 21 to 23, the drive mechanism being arranged to act on the further levers in a direction which is different to that in which it acts on the first mentioned levers.
- 5 25. A positioner according to any of claims 21 to 24, each of the further levers being aligned with a corresponding one of the first mentioned levers.
26. A positioner according to any of claims 21 to 25, the further levers being connected together by a flexible hinge.
- 10 27. A positioner according to claim 26, wherein the further levers are formed from a single cross member, the flexible hinge being provided by a thinned section of the cross member.
- 15 28. A positioner according to any of claims 22 to 27 when dependent on claim 8, the support walls also supporting the further levers, the further levers being connected to the support walls by flexible connections for providing the fulcrums.
- 20 29. A positioner according to claim 28, wherein each further lever and its support wall are of unitary construction, the flexible connection being provided by a thinned section at their junction.
30. A positioner according to claim 28 or 29, wherein the first mentioned, levers, the support walls and the further levers are of unitary construction.
- 25 31. A positioner according to any of claims 21 to 30, wherein the further levers are connected to the base by a pair of input linkages which are stiff in respect of forces applied along their axes of extent.
- 30 32. A positioner according to claim 31, wherein the input linkages are deformable in respect of forces applied transverse to their axes of extent.

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33. A positioner according to claim 31 or 32, wherein the input linkages extend away from the input levers on the same side as that on which the drive mechanism is located.

5

34. A positioner according to any of claims 31 to 33, wherein the input linkages extend substantially parallel to a drive axis along which the drive mechanism supplies an actuation force.

10 35. A positioner according to any of claims 21 to 34, further comprising biasing elements connected to each further lever and arranged to resist movement of the further levers relative to the base and so provide a restoring force when the further levers are moved.

15 36. A positioner according to any of claims 21 to 35, further comprising a mechanical stop connected to each further lever to limit the amount by which it can move relative to the base.

20 37. A positioner according to any of claims 21 to 36, further comprising one or more strain gauges for measuring the positions of the further levers.

38. A positioner according to claim 37, wherein the one or more strain gauges are coupled to respective bridge measuring circuits mounted on the positioner.

25 39. A multi-axis positioner comprising a first positioner according to any of claims 1 to 38 aligned along a first direction and a second positioner according to any of claims 1 to 38 aligned along a second, different, direction, the first and second positioners connecting between a common base and a common sample platform.

30 40. A multi-axis positioner according to claim 39, wherein the first direction and the second direction are orthogonal to one another.

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41. A multi-axis positioner according to claim 39 or 40, further comprising a third
positioner according to any of claims 1 to 38 aligned along a third direction, the third
direction being different to the first and second directions, the third positioner
5 connecting between the common base and the common sample platform.

42. A multi-axis positioner according to claim 41, wherein the third direction is
orthogonally arranged with respect to at least one of the first or second directions.

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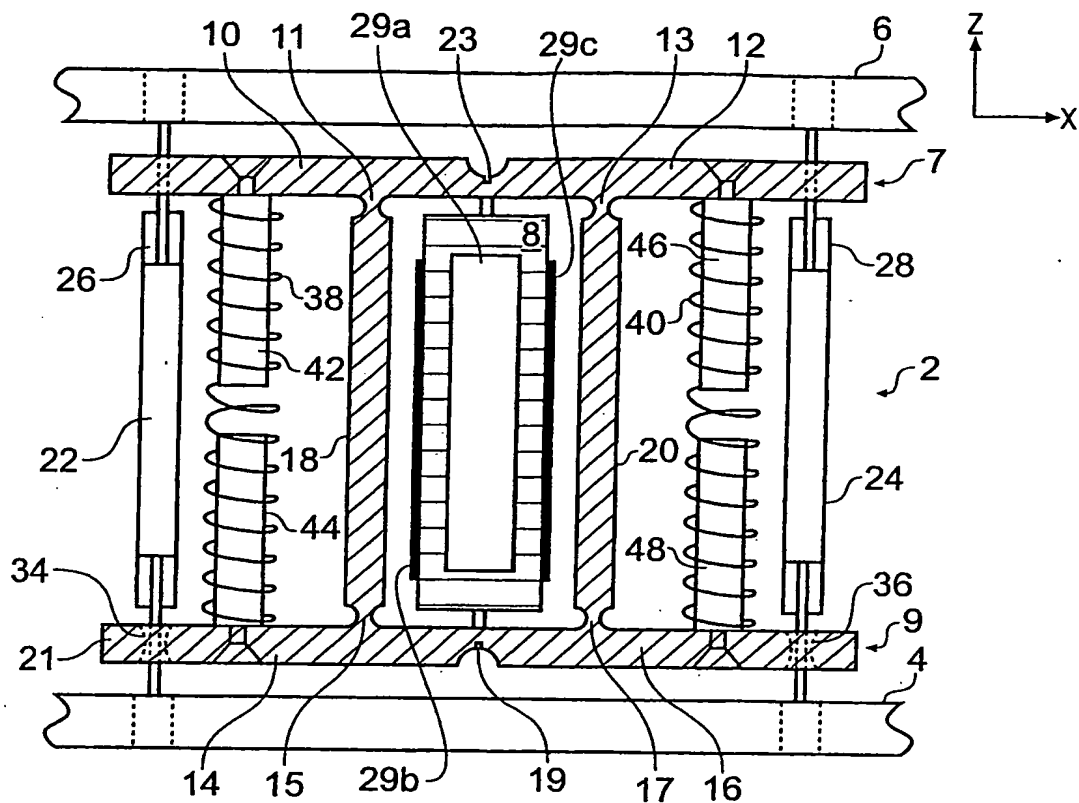
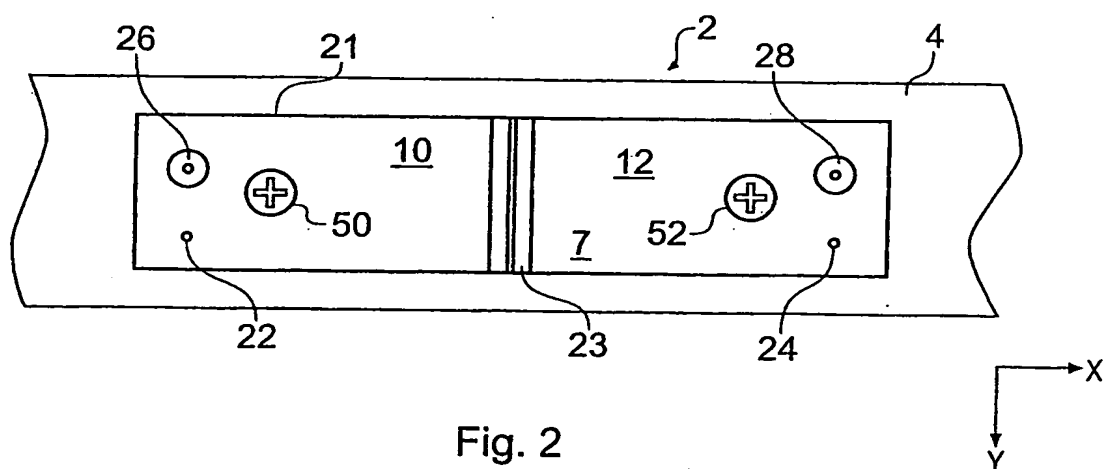


Fig. 1



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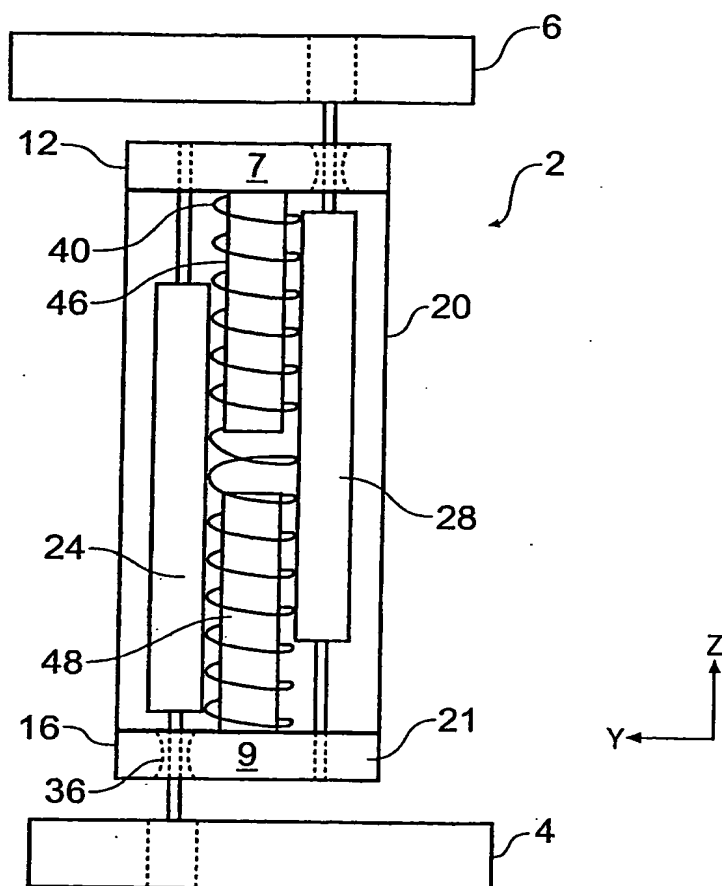


Fig. 3

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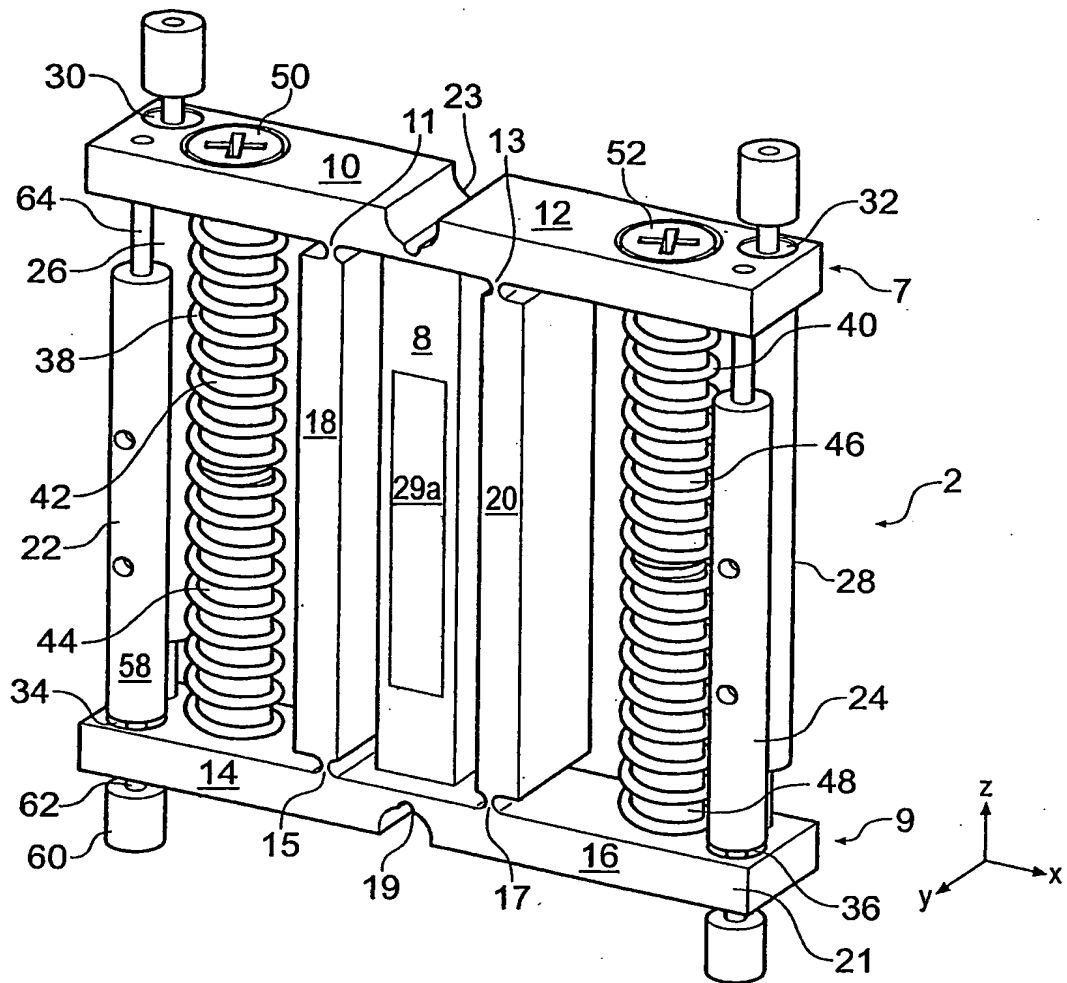


Fig. 4

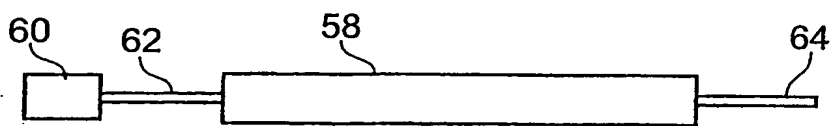


Fig. 5

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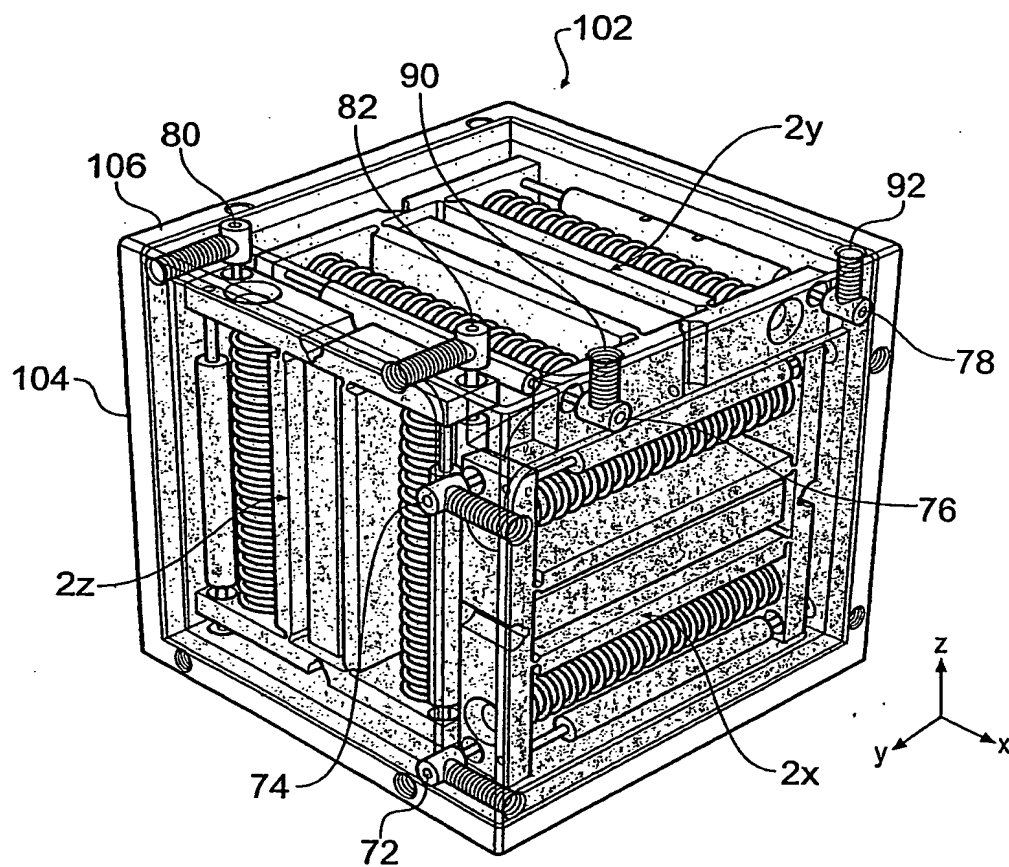


Fig. 6

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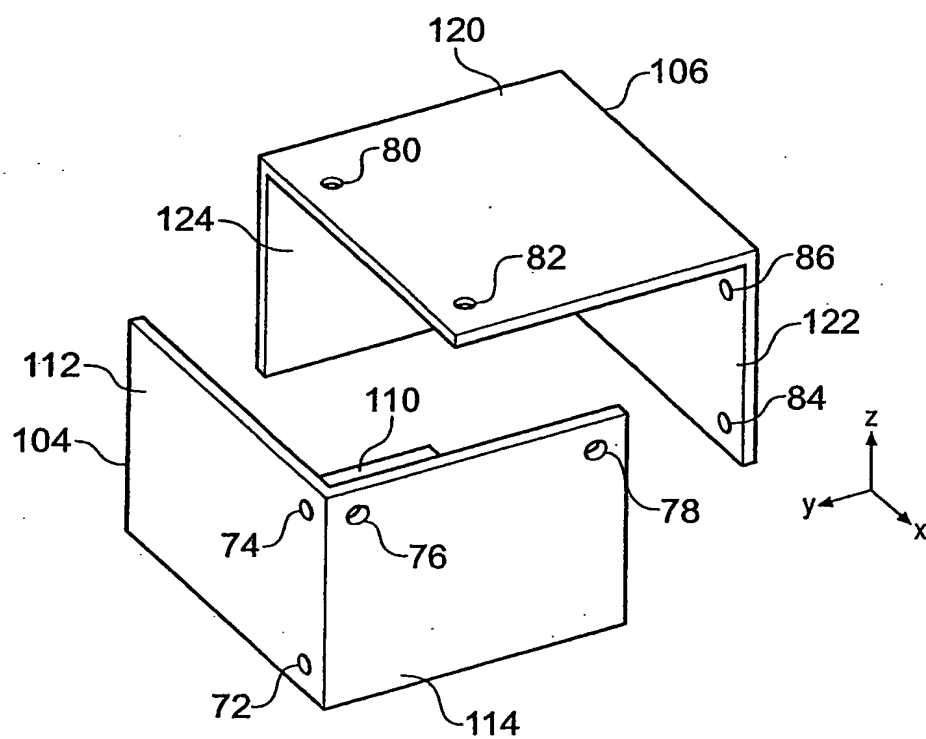
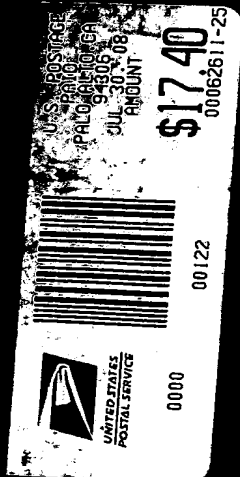
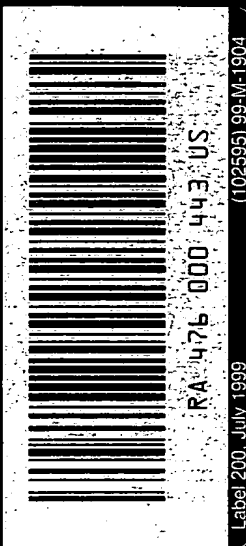


Fig. 7



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EMPLOYEE'S NAME : Terry HERBERT

ORIGINAL DATE OF COMMENCEMENT OF EMPLOYMENT : 1 August 1996

DATE OF TRANSFER TO ENGINEERING DEPARTMENT : 17 August 2001

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- 2.1. You will normally work a 37½ hour week of five days Monday to Friday inclusive.

- 2.2. Your normal starting time is 9.00 a.m. and your normal finishing time is 5.30 p.m. Monday to Friday with an unpaid lunch break of one hour each day.
- 2.3. You will be expected to work overtime from time to time as the workload so requires and this has been taken into consideration in setting your salary.
- 2.4. There is no formal break outside of the lunch period and you are expected to consume any beverages at your place of work.
- 2.5. By agreement with the Managing Director your starting and finishing time may be varied to 8.30 a.m. to 5.00 p.m.

3. HOLIDAYS AND HOLIDAY PAY

- 3.1. The holiday year is from January to December each year.
- 3.2. The full annual entitlement is 25 working days with pay per year.
- 3.3. Employees joining or leaving the Company during the year will be entitled to a proportion of their full entitlement of paid holiday calculated on a pro rata basis per completed calendar month of service.
- 3.4. Your annual holiday entitlement accrues at the rate of 2.08 days per calendar month which equals 25 days per year.
- 3.5. You are not eligible for holiday entitlement unless you have completed three months continuous service, at which time your entitlement will be calculated from your date of commencement of employment.
- 3.6. In addition to the above, you will also receive a paid holiday on or in respect of each of the eight Public Holidays as listed below:

New Year's Day
Good Friday
Easter Monday
May Day

Spring Bank Holiday
Late Summer Holiday
Christmas Day
Boxing Day

- 3.7. Payment for all holidays is calculated on basic rate of pay.
- 3.8. Should you leave the Company for whatever reason and holidays taken exceed entitlements, then you accept as part of these Conditions of Employment that the Company has the right to deduct payments made in excess from any monies owing to you at the time of leaving.
- 3.9. The Company encourages all employees to take their full holiday entitlement in the holiday year. If you do not take all your holiday entitlement in any one holiday year you may carry forward up to 5 days into the following year. In general no payment in lieu of holiday entitlement will be made except on leaving the Company

4. **SICK PAY SCHEME**

- 4.1. The Company operates a discretionary Sick Pay Scheme. Details as described in the Handbook of Company Procedures.

5. **PENSION SCHEME**

- 5.1. All employees are contracted into the State Pension Scheme for the purposes of the Social Security Contributions & Benefits Act 1992. Contracting out may be affected by means of a personal pension, details of which will be provided.
- 5.2. The company operates a money purchase occupational pension scheme to which it contributes 5% of employee's salary. Employees are required to contribute a minimum of 2.5% if they elect to join. Staff may join the scheme at either of the review dates, which are 1st June and 1st December each year.

6. **MEDICAL INSURANCE AND DEATH IN SERVICE**

- 6.1. The company provides private medical insurance cover for all staff and this may be extended to cover employee's immediate families upon payment of the appropriate premium.
- 6.2. The company operates a combined Permanent Health Insurance scheme together with a death in service scheme and critical illness cover for all staff. A menu of options is available to best suit each employee. Full details are available from the P.A. to the Managing Director.

7. **GRIEVANCES**

- 7.1. The Company's grievance procedure is as detailed in the Handbook of Company Procedures.

8. **DISCIPLINARY PROCEDURES**

- 8.1. The main disciplinary procedures of the Company are as detailed in the Handbook of Company Procedures.

9. **TERMINATION OF EMPLOYMENT**

- 9.1. The Company is required to give you, after one month's continuous service, the following notice in writing according to your length of service as follows:
- 9.1.1 Up to six months' continuous service1 week
- 9.1.2 After six months' continuous service but less
than five years' continuous service4 weeks

- 9.1.3 Then increasing by one week for each completed year of continuous service up to a maximum entitlement of ...12 weeks
- 9.2. You are required to give the Company, after six month's continuous service, the same notice of termination as the Company is required to give you.
- 9.3. If you give notice to the Company to terminate your employment or you are given notice by the Company, it may be possible, by mutual agreement, to waive the formal periods of notice.
- 9.4. The Company has the right to dismiss employees without notice in the case of gross misconduct.
10. **DECLARATION**
- I accept this Statement, a copy of which has been given to me.
- I have also received a copy of the Handbook of Company Procedures which I understand is part of my "Terms of Employment".
- Signed: T. Herbert Dated: 6-8-01



PATENT
Customer No. 22,852
Attorney Docket No. 9314.0046-00

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:)
)
Michael John DIXON et al.) Group Art Unit: 2834
)
Application No.: 10/589,684) Examiner: Not Yet Assigned
)
Filed: January 31, 2005)
) Confirmation No.: 9914
For: POSITIONER DEVICE)

MAIL STOP AMENDMENT

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

DECLARATION OF KEITH DHESE

I, Keith Dhesse, do hereby make the following declaration:

1. I am employed by Thorlabs Ltd., the U.K. operations manufacturing facility of Thorlabs, Inc.
2. On April 2, 2008, I was asked to assist in obtaining the signature of Terence James Herbert on the Declaration and Power of Attorney document in order to respond to a Notice of Missing Requirements issued on March 20, 2008, by the United States Patent and Trademark Office, as well as for an Assignment document, in connection with the subject patent application. The application names Michael John Dixon and Terence James Herbert as inventors.
3. In late April 2008, I asked Mr. Gordon Chapman, a friend of Mr. Herbert, to contact Mr. Herbert and ask him about signing the above-mentioned documents. Mr. Chapman

indicated that Mr. Herbert probably would not sign, but he would ask anyway. At the time, Mr. Chapman was employed by Thorlabs, Ltd., but has since terminated his employment.

4. On May 9, 2008, I e-mailed Mr. Herbert directly at THerbert@kerr-noble.com. This e-mail address was provided to me by Mr. Gordon Chapman. To this date, I have not received a response to my e-mail.

5. On May 16, 2008, I managed to get a hold of Mr. Herbert on his mobile phone. This telephone call was initiated by Allison Killock, a friend of Mr. Herbert. During this call, Mr. Herbert indicated that he would sign the papers. Ms. Killock is currently employed by Thorlabs, Ltd.

6. Subsequent attempts in late May and early June by me and Ms. Killock to follow up with Mr. Herbert to coordinate the signing of the papers were unsuccessful.

7. Based on the fact that Mr. Herbert has not responded to my initial e-mail of May 9, 2008, and subsequent attempts to reach him by me and Ms. Killock proved unsuccessful, it is my opinion that Mr. Herbert may be adverse to signing the above-mentioned documents for reasons not known to me.

I further declare that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true, and understand that willful false statements and the like are punishable by fine or imprisonment, or both (18 U.S.C. 1001), and may jeopardize the enforceability of any patent issuing from the '684 application.

Dated: 18th SEPT 2008

By: Keith Dhesse
Keith Dhesse
Thorlabs, GmbH